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Special Issue
Through-knee Amputation
and Prosthetics

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Contents

Executive Board of ISPO

Editorial

ISPO arranged an advanced course on below-knee and through-knee amputations and prosthetics in May 1982 in Denmark. As a limited number of publications about the knee disarticulation has appeared during the past decades it was decided to present the different aspects of through-knee amputation and prosthetics in a special issue of our Journal.

It must be remembered that the selection of amputation level should primarily be based on the circulatory conditions of the limb, whereas the prosthetic considerations are of minor importance in that regard. There is no doubt that the lack of popularity of the through-knee amputation is related to the cosmetic problems and possibly the difficulties of manufacturing a comfortable and well functioning prosthesis, although the amputation stump is end-bearing and has numerous advantages.

This issue will describe not only the epidemiology, modern aspects of level determination and immediate postoperative treatment, but also the details of the prosthetic practice. In contrast to other previous publications the achieved gait rehabilitation as well as the life expectancy and living conditions will also be described and compared to the above-knee and below-knee levels, which are predominantly applied internationally for vascular and diabetic gangrene of the lower limb.

The main purpose of this issue is to highlight the advantages of the knee disarticulation. In modern amputation surgery the through-knee level should be considered along with the above-knee and below-knee levels. A suitable prosthesis should be manufactured, not as a technical exercise, but in consideration of the general condition and physiological abilities of the patient. It is my hope that these messages will be understood and the percentage of through-knee amputations will increase for the benefit of a successful rehabilitation of our amputees.

J. Steen Jensen,
Guest Editor.

Choice of level in lower extremity amputation —nationwide survey

B. EBSKOV

Danish Amputation Register, Copenhagen

Abstract

This survey analyses the levels of all major lower limb amputations in Denmark performed in 1980. During that year a total of 2,404 amputations were carried out on 2,177 patients.

Introduction

Generally the title: "Choice of Level in Amputation" evokes associations of clinical or technical aids in choosing the proper level. Most, if not all, publications on lower limb amputation are garnished with tabulations of the levels chosen. Their quality notwithstanding, such publications are invariably based upon highly selected population samples. It is often attempted from the samples, with the application of more or less sophisticated statistical tools, to deduce a "general" picture. Until now it has not been possible to verify such generalizations.

The present study describes the nationwide pattern of lower limb amputation in Denmark.

Method and material

Since 1976 the Danish State Board of Health has collected information on all hospital admissions in the country.

The individual patient records are fed into a computer system, the so-called National Patient Register (NPR).

For scientific study individuals and medical organizations may obtain specified listings of the NPR, stored on magnetic tape or printed out according to the needs of the requestor. Naturally a strict set of rules must be adhered to, in order to maintain the privacy of the individual.

All correspondence to be addressed to Dr. B. Ebskov, The Danish Amputation Register, P.O. Box 899, DK-2100, Copenhagen, Denmark.

Since 1972 the Danish Amputation Register (DAR) has conducted studies in all aspects of amputation (Eskov, 1977). Originally the major source of information was voluntary reports from orthopaedic and surgical departments. In recent years the DAR has had access to the relevant material obtainable from the NPR.

The actual tabulations and analyses are performed on a microcomputer-system (Apple II Plus), hooked up to the mainframe (CDC Cyber) of the State University Hospital (Rigshospitalet) in Copenhagen.

The study is based upon information of all major (i.e. at or proximal to the transmetatarsal level) amputations during the year of 1980.

Results

During 1980 2,404 major amputations were carried out in 2,177 patients (Table 1, Fig. 1).

In the majority, 88·2%, the indication was vascular insufficiency. One third of these patients suffered from diabetes mellitus. Trauma

Fig. 1. Etiology.

Table 1. Total number of amputees and amputations during 1980. Distributed by etiology.

	Patients	Amputa-tions	
01 Vascular Insufficiency	1319	1457	60·6%
02 VI+Diabetes Mellitus	601	672	27·6%
03 Trauma	94	97	
04 Benign Tumour	0		
05 Malignant Tumour	33	34	
06 Congenital Deformity	6	6	
07 Congenital Amputation	0		11·8%
08 Infection	47	55	
09 Pseudoarthrosis	0		
10 Miscellaneous	77	83	
Totals	2177	2404	

only accounted for four per cent of all amputations.

For the most significant etiologies, i.e. groups 1 and 2, details are given regarding age and sex distribution (Figs. 2 and 3), level of amputation (Tables 2 and 3), duration of hospitalization (Figs. 4 and 5) and details of dismissal from hospital, including intranosocomial mortality (Tables 4 and 5).
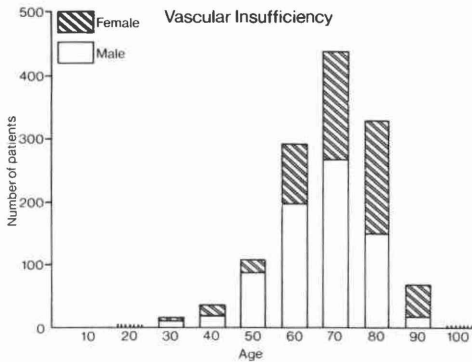
Fig. 2. Vascular insufficiency related to age and sex.
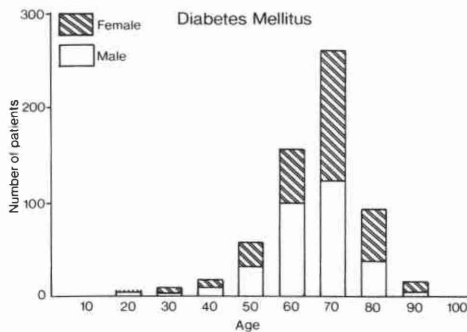
Fig. 3. Diabetes mellitus related to age and sex.

Table 2.
Level of amputation for vascular insufficiency.

Level	1	2	3	Total	%
Foot	36	6	2	44	3·0
Syme	5	1		6	0·4
B K	480	51	6	537	36·9
T K	30	6		36	2·5
A K	768	61	5	834	57·2
Totals	1,319	125	13	1,457	

Amputees with vascular insufficiency (VI), without or with concommittant diabetes mellitus (DM), belong in the older age groups, 8 and 9, respectively 87% being more than 60 years old.

The sex distribution is surprisingly similar in both groups, with males accounting for 51 (DM) to 58 (VI) per cent of the total.

The level of amputation is obviously different from patients with simple vascular insufficiency to diabetics. In the former, amputation at foot level was carried out in 3·4% of patients, in the diabetic group in 10·9%. Below-knee amputation was carried out in more than half of the diabetic patients (53·6%), versus one third (36·9%) in those with simple VI Correspondingly, 57·2% of the VI patients were amputated above the knee, versus only 34% in the DM group.

It is striking that the rate of through-knee amputation was respectively 2·5% and 1·5%. Considering the excellent prostheses available to TK amputees, the application of this type of surgery is surprisingly rare.

An assessment of levels of amputation in females and males respectively shows that within the same etiological group there is virtually no difference.

Tables 2 and 3 show the number of patients, operated one to three times during the same admission. Since the NPR does not hold information on the date of operation, nor on laterality, it is not possible, based upon the

Table 3. Level of amputation for diabetes mellitus.

Level	1	2	3	Total	%
Foot	66	4		70	10·4
Syme	3			3	0·5
B K	317	42	1	360	53·6
T K	9	1		10	1·5
A K	206	20	3	229	34·0
Totals	601	67	4	672	
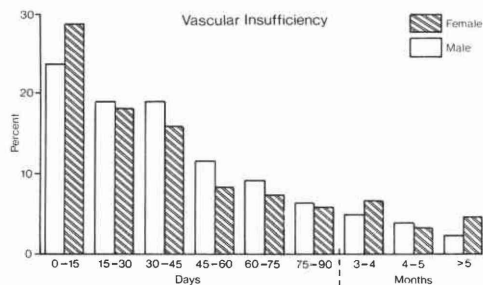
Fig. 4. Vascular insufficiency, duration of stay in hospital.
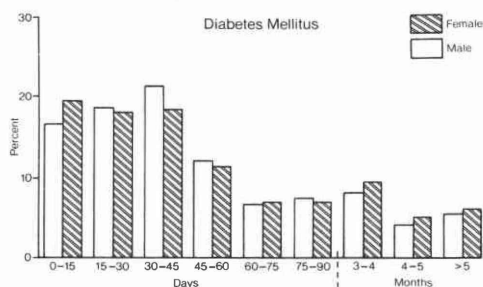
Fig. 5. Diabetes mellitus, duration of stay in hospital.

lapse of time from amputation to death in hospital has not been analysed.

Table 4. Dismissal (including mortality)—vascular insufficiency.

	M	F	Total	
Home	314	252	566	42·9%
Other Department	149	105	254	
Other Hospital	82	56	138	
Nursing Home	122	82	204	15·5%
Recreation	7	3	10	
Miscellaneous	2	1	3	
Dead	88	56	144	10·9%

Table 5. Dismissal (including mortality)—vascular insufficiency with diabetes.

	M	F	Total	
Home	138	121	259	43·1%
Other Department	50	56	106	
Other Hospital	48	23	71	
Nursing Home	35	58	93	15·5%
Recreation	2	1	3	
Miscellaneous	2	1	3	
Dead	34	31	65	10·8%
Unknown		1	1	

present material, to extract details of the absolute incidence of contra- or ipsilateral re-amputation. This topic was analysed in an earlier work (Ebskov, 1980).

The duration of hospitalization was tabulated for males and females. It turns out that in VI as well as in DM there is a remarkable similarity between the sexes. Approximately 40% of all amputees were dismissed before the end of the first postoperative month and about 75% of all prior to the elapse of 2 months.

Similarly a large number of patients (better than 40%) were dismissed directly to their own home. About 15% had to be transferred to a nursing home. These findings seem rather remarkable considering the large number of older patients in these etiological groups. Since patients in Denmark are not charged for the admission or treatment, economical consider-ations on the part of the patients cannot be the explanation.

The intranosocomial mortality was slightly above 10% in both groups, again with no convincing difference between the sexes. The

Conclusion

The present study represents solely a superficial scanning of the National amputation patterns. At present more detailed studies are under way.

It is anticipated that the Danish Amputation Register can contribute not only significant details of many aspects of amputation, but furthermore in the future open the possibility of trend analyses.

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The healing of through-knee amputations in relation to skin perfusion pressure

H. C. THYREGOD, P. HOLSTEIN AND J. STEEN JENSEN

*Department of Orthopaedic Surgery T–2, Gentofte Hospital,
Department of Clinical Physiology, Glostrup Hospital and Bispebjerg Hospital,
University of Copenhagen*

Abstract
The healing in 20 through-knee amputations was compared with preoperatively measured skin perfusion pressure, determined as the minimal external pressure required to stop the washout of isotopes injected intradermally 10 cm distal to the knee joint. Out of 18 amputations with a skin perfusion pressure of above 20 mmHg only 2 failed to heal, whereas 2 out of 4 cases with skin perfusion pressure below 20 mmHg failed to heal. It is concluded that the through-knee amputation must be considered in cases where the circulation is borderline for healing in below-knee amputation.

Introduction

Skin perfusion pressure (SPP) measured by radioactive isotopes has been used in the determination of level in major amputation since 1972 (Holstein, 1973) and the predictive value as regards the healing in below-knee (BK) and above-knee (AK) amputations has been demonstrated (Holstein et al, 1979 a, b; Kolind -Sørensen and Marqversen, 1979; Holstein, 1982). The purpose of this paper is to compare the healing of through-knee (TK) amputations with preoperatively measured SPP.

Patients and methods

During a 7 year period (1.1.1973 to 1.1.1980) 20 TK amputations were carried out after measurement of the local SPP in 20 patients with occlusive arterial disease with gangrene. The arithmetic mean age of the patients was 73 years (range 56–91). Three of the patients had diabetes

All correspondence to be addressed to Dr. P. Holstein, Bredland 3, 2850 Naerum, Denmark.

mellitus. The surgical technique included bilateral flaps (Kjølbye, 1970) with a sagittal suture line. Suction drainage was used when necessary and preoperative antibiotics were not used. The postoperative dressing was a loosely applied elastic band. Sutures were removed on the 21st day. The patients were mobilized as soon as possible in a wheelchair or preferably on walking appliances. Prosthetic fitting was made when the stump was mature.

Measurement of the SPP

The principle has recently been described (Holstein, 1980) and will only be summarized. About 0·1 ml of a radioactive tracer—histamine mixture is injected intradermally. The tracer used is either ^{131}I–antpyrine (10–20 μ Ci) or ^{99m} pertechnetate (50 μ Ci). The washout is measured with conventional scintillation detector and counting equipment. A semilogarithmic curve is written on a penwriter. By means of a blood pressure cuff placed directly on the depot external pressure is applied to the labelled skin and kept constant. By raising the pressure stepwise the washout decreases and the SPP is defined as the minimal external pressure required to stop the washout. The pressure intervals used are 5 mm Hg. It is most important to immobilize the leg completely during the procedure with sandbags. Since the procedure causes pain analgesics are practically always given (Demerole 35 mg i.v. in repeated doses). The sites of measurements have been standardized: the dorsum of the foot, the anterolateral part of the calf 10 cm distal to the knee joint and the anterolateral part of the thigh 10 cm proximal to the knee joint. In most cases the situation is sufficiently elucidated by one

measurement, i.e. the standard site 10 cm below the knee. A total mapping out of the limb is rarely indicated.

Results

Table 1 shows the results as regards healing. Below 20 mm Hg 2 stumps out of 4 failed to heal. One stump healed by second intention and one stump healed primarily. Between 20 and 30 mm Hg one stump out of 6 failed to heal and above 30 mm Hg one stump out of 10 failed to heal. The 14 successful stumps with SPP above 20 mm Hg healed by primary intention.

The correlation between wound complications and SPP as evaluated by a rank sum test was almost statistically significant (P   0·07).

Discussion

In this study the healing of TK amputations has been compared to the preoperative SPP as measured 10 cm below the knee joint, i.e. the point usually employed for determination of healing prognosis for BK amputations. SPP values below 20 mmHg at this point means 75 to 90 per cent risk of failure and SPP values between 20 and 30 mm Hg means about 50 per cent risk of failure (Holstein et al, 1979; Holstein, 1982). TK amputations are made a little more proximally, and if no specific complications related to the TK level appear, one would expect a slightly better healing prognosis for this type of amputation as related to the measure point 10 cm below the knee. In fact the healing figures were slightly better with 50 per cent risk of failures below 20 mm Hg and 17 per cent risk of failures between 20 and 30 mm Hg. The TK amputations as well as the BK amputations heal in approximately 90 per cent of the cases in non-ischaemic tissue, i.e. with SPP above 30 mm Hg.

Primary healing took place in all but one of the maintained TK levels. This is in contrast to the BK amputations where previous series demonstrated a high frequency of minor wound complications (Holstein et al, 1979; Holstein, 1982). Although the TK amputation is made with a minimum of soft tissue covering a large bulky triangular hard surface, the stump seems to be more resistant than a BK stump during the healing phase. Moreover rehabilitation as regards walking with a prosthesis is about equal in patients with TK and BK amputations (Steen Jensen et al, 1983). For these reasons the TK

amputation must be considered an alternative to the BK amputation, first of all in cases where the SPP is borderline for healing of a BK stump, i.e. at SPP of 20 to 30 (40) mm Hg. However, the TK amputation should also be considered when the SPP practically excludes healing at BK level, i.e. at SPP below 20 mm Hg; this situation can probably be further evaluated by measurements on the thigh or perhaps at the level of the knee joint.

Table 1. The number of healed TK amputations in relation to the total number and in relation to the skin perfusion pressure (SPP).

	SPP		
	< 20 mmHg	20–30 mmHg	> 30 mmHg
Without diabetes mellitus	1/3	4/5	8/9
With diabetes mellitus	1/1	1/1	1/1
Total	2/4	5/6	9/10

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Preliminary experiences with laser Doppler velocimetry for the determination of amputation levels

G. A. HOLLOWAY, Jr. and E. M. BURGESS

Center for Bioengineering, University of Washington, Seattle

Abstract

Laser Doppler velocimetry is a newly available technique for the continuous and non-invasive measurement of capillary perfusion. The technique is presented and preliminary results of its use in the evaluation of amputation levels in 16 patients discussed.

Introduction

A large number of amputations are performed worldwide each year, exceeding 100,000 in the United States alone. Decisions as to when to amputate and at what level have become an important surgical problem. Most of the amputations are being carried out for atherosclerotic ischaemic vascular disease of the lower limb in an ageing population.

The success of rehabilitation following an amputation in this population is related to many factors but certainly among the most important is the level at which the amputation is performed. The lower the level, the greater the chance of successful rehabilitation and independent living. It therefore becomes of great importance to be able to accurately assess the level at which the least destructive surgery can be carried out.

Experience with present methods

Over the years, a multitude of methods to predict the success or failure of a given level of amputation have been advanced and applied Burgess and Matsen (1981) in a recent review have discussed this problem and concluded that none of the methods have proven ideal. Evaluation of clinical symptoms and signs has been the standard way of evaluating a limb for the presence or absence of vascular disease, and

if an amputation was indicated, what would be the most satisfactory level for healing. Clinical signs however are heavily subjective, and are frequently of value only in experienced hands.

Beginning in the late nineteenth century and continuing to the present a variety of techniques have been introduced to evaluate the viability of a limb using more objective techniques and technologies. These have included measurement of various aspects of blood flow, blood pressure, and delivery or removal of metabolic substances. Some of these have become more standardly used than others. Venous occlusion plethysmogaphy has become more or less the physiological standard for measuring volumetric blood flow in a limb (Summer, 1982). This technique however is cumbersome clinically and cannot be utilized on all locations where one might wish to measure blood flow. There is also the question as to whether the inflation and deflation of cuffs on the limb causes changes in the blood flow being measured. A second technique is that of segmental blood pressure (Yao and Takaki, 1982). It is now well known however that in both diabetics and nondiabetics the major arteries may be calcified and stiff and cannot be compressed giving an artificially high pressure at that level. Radioisotope clearance has also been used fairly extensively but is both invasive and requires exposure to radiochemicals although frequently relatively minimal. Again, evidence suggests that the blood flow being measured is altered by the technique (Holloway, 1980). More recently the partial pressure of oxygen has been measured at the skin surface as an indicator of the oxygen level in the capillary system (Matsen et al, 1980). This system has proved of some value although it is limited by the fact that it cannot be used on every surface, and tha the skin must be heated before a value can be obtained.
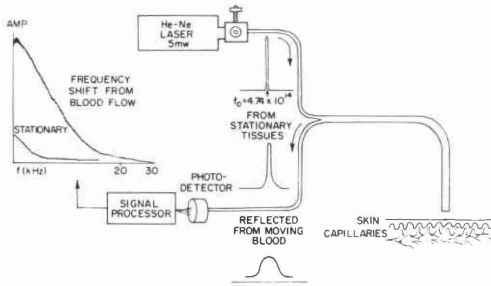
Fig. 1. Block diagram of laser Doppler system. See text for detailed explanation.

It is the purpose of this paper to review an additional technique, laser Doppler volocimetry (Stern et al, 1977; Watkins and Holloway, 1978; Nillson et al, 1980) for its potential use in evaluating ischaemic vascular disease and amputation levels. As it is noninvasive, continuous, and has a small sample volume, its consideration for use in evaluation of ischaemia and amputation levels appears warranted.

Laser Doppler principles and methods

Laser Doppler velocimetry is a technique which uses the Doppler principle much as the ultrasonic Doppler does, but uses light instead of sound. A simplified block diagram is shown in Figure 1. A low power laser provides the source of monochromatic (single frequency) light which is led to the skin surface through a small glass optical fibre. As the light impinges on the skin surface it is backscattered as two components as indicated in Figure 2. The first is light backscattered from the non-moving structures in the surface layers of the skin and is therefore not Doppler shifted. The second component is backscattered from moving red blood cells in the superficial capillaries in the skin and is Doppler shifted in frequency in accordance with the velocities of the red blood cells. Both of these components are returned from the skin surface through a second optical fibre to a photodetector. Both the Doppler shifted and non-Doppler shifted components mix together on the surface of the photodetector and constructively and destructively interfere. The frequency at which this interference occurs is the Doppler shift frequency. However as the light is backscattered from many different red cells moving at different velocities, a single frequency is not present, in fact a spectrum of frequencies is observed. The electronic signal carrying these frequencies is then processed with the output of this circuit being a single number which has been shown to vary directly with flow as measured by other "standard" methods. This output is then displayed either on a panel meter or a strip chart recorder. The actual probe containing the two optical fibres is simple and light in weight and can be either set upon the skin surface or more tightly attached using double sided cellophane tape. With the probe on the skin surface a continuous and noninvasive measure of capillary blood flow in a sample volume of approximately one cubic millimeter is made. Figure 3 shows the instrument in use.
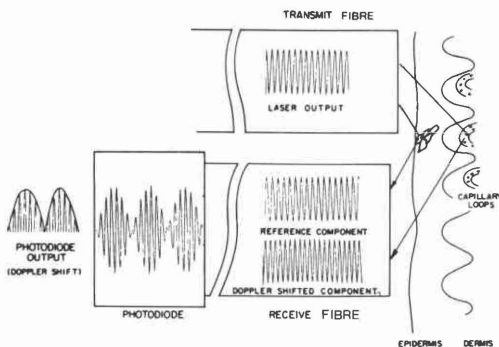
Fig. 2. Diagram of laser Doppler optical mixing process. "Reference" light from non-moving tissues is mixed on the photodetector with Doppler shifted light scattered from moving red blood cells. The interference pattern produced is seen in the envelope of the photodetector output, and is the Doppler shifted frequency.
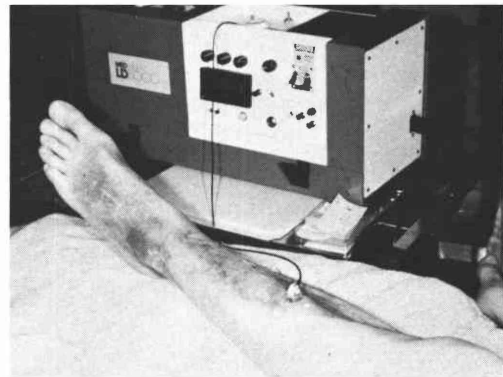
Fig. 3. Laser Doppler velocimeter in use. (With permission from Holloway, G. A. (1983) Laser Doppler measurement of cutaneous blood flow. In: Rolfe, P. (ed) Non-invasive Physiological Instrumentation, Vol. II. London, Academic Press. (in press). Copyright, Academic Press Inc. (London) Ltd.

Comparison with other methods

Laser Doppler velocimetry has been compared with several other methods for the measurement of blood flow. It is important to realize however that the sample volumes and the quantities being measured in these other methods all differ to some degree. Firstly laser Doppler velocimetry has been compared to the clearance of the radioisotope xenon on several occasions (Stern et al, 1977; Watkins and Holloway, 1978). These comparisons have shown a linear relationship between the two techniques but with a fair amount of variance. The methods differ in that the sample volume from the xenon clearance is in the order of one cubic centimeter and the technique is only valid during the rapid clearance phase of xenon. It also appears to be influenced by the method used to apply the xenon (Holloway, 1980).

The laser Doppler technique has also been compared to flow as measured by microsphere deposition. Stern et al (1979) measured flow through the renal ·cortex using both laser Doppler and radioactively labelled microspheres as well as an electromagnetic flow meter on the renal artery. The laser Doppler instrument used had a slightly different processing algorithm than present instruments but showed a generally linear relation to flow as measured by either microspheres or electromagnetic flow meter but a tendency to underestimate flow in high flow states. These studies using microspheres have not been repeated in the skin, and no studies have been done comparing laser Doppler instruments with the newer processing techniques with microspheres.

Two recent studies have been done in the gastrointestinal tract comparing laser Doppler velocimetry with measurements made using an electromagnetic flow meter placed on the mesenteric artery to that segment (Feld et al, 1982; Shepherd and Riedel, 1982).

When the laser Doppler was placed on the mucosal surface, changes in total blood flow as measured with the electromagnetic flow meter correlated well with local mucosal flow changes as measured by the laser Doppler system. It is important again to note that the laser Doppler, microsphere technique, and electromagnetic flow meter are all measuring different quantities. Thus although the correlation between the techniques is good one cannot calibrate the laser Doppler as a measurement of capillary flow

against these other methods. There is in fact no model system for a capillary network as appears in the skin which will permit callibration of the laser Doppler in absolute flow. On the other hand work by Bonner and Nossal (1981) has suggested that the laser Doppler does indeed provide a quantitative measure of instantaneous microvascular blood flow in optically accessible tissues.

Clinical experience

As the laser Doppler instrument has only been recently available clinical experience in patients with ischaemic vascular disease in the determination of amputation levels has been limited. Our experience has been limited to sixteen patients undergoing twenty amputations; eight were diabetic and eight nondiabetic. The amputations performed were: one Raye, one transmetatarsal, four Syme, eight below-knee (BK) and six above-knee (AK). The first studies were done with a prototype laser Doppler instrument but subsequently a new commercially available instrument with a slightly different processing algorithm has been used.* As the algorithms are different, the flow values scale differently and thus values from one machine cannot be well compared with those from the other. In addition only partial data is available on some of the patients. The patients have varied in age from 29 to 94. The protocol used evaluated both resting and heated flow as well as transcutaneous Po_2 at the dorsum, BK, and AK levels. Heating was performed to test for flow reserve with the heated flow value being measured in the centre of the area where the transcutaneous oxygen heater had been at 44°C for ten minutes.

Of the 20 amputations performed, all fourteen performed at either BK or AK levels healed satisfactorily and primarily. The Raye, transmetatarsal and two of the Syme amputations failed. In the failed Raye and both Syme amputations resting flow was about the same as in normals, but heated flow increased only minimally and to a level less than one third of that seen in normals. Transcutaneous Po_2 values were highly variable in all three. The transmetatarsal amputation had good values for

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* The laser Doppler velocimetry instrument used was the LD5000 Capillary Perfusion Monitor manufactured by MEDPACIFIC Inc., 6701 6th Ave. So., Seattle, Wash. 98108. List price: $13,500.

both resting and heated flow as well as transcutaneous Po_2. This amputation was performed for pressure induced ischaemic ulcers and was healing relatively well at that level but a nonhealing ulcer eroding down to the Achilles tendon made it clinically advisable to revise it to a BK level. All of the patients having amputations at the BK or AK level in whom technically adequate flow readings were obtained showed a significant increase in the heated flow value as compared to the resting level, although less than seen in normals.

Our initial data would therefore support the continued trial of the laser Doppler velocimeter in the evaluation of amputation levels for ischaemic vascular disease. Although the resting values are in the same range as those for normals, values after heating to 44°C for ten minutes showed markedly diminished hyperemic response as compared to normals, especially in those patients who failed to heal their amputations primarily. It has not yet been determined what levels define the cutoff between amputations which heal and those which do not. It is felt that now the instrumentation is being better standardized and when more patients are evaluated, critical flow levels will be able to be indentified.

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An index to measure the healing potential of ischaemic ulcers using Thallium 201

M. E. SIEGEL, C. A. STEWART, F. W. WAGNER, Jr. and I. SAKIMURA

University of Southern California School of Medicine, Rancho Los Amigos Hospital, California

Abstract
Prediction of healing of ulcers in ischaemic limbs can preclude unnecessary treatment for ulcers that cannot heal. Non-invasive methods are of marked value as the ischaemic limb is susceptible to further ulceration from local skin penetration. Relative hyperemia of the ulcer was measured by scintillation count over the ulcer and at points 2.5 cm from the edge of the ulcer. Relative hyperemia was determined by dividing the count per unit area of the ulcer by the counts per unit area of the surrounding tissue. All ulcers with a relative hyperemia over 1.5 healed.

Introduction
Ischaemic changes of the lower extremities leading to ulceration, infection, and gangrene now account for 70–90% of lower limb amputations in the United States. These surgical procedures account for approximately 0.5% of all operations performed (Warren and Kilhn, 1968).

In the past 30–40 years there has been a marked shift in the ratio of above-knee to below-knee amputations. At one time 80% of all amputations for lower limb ischaemia were performed above the knee. With the increasing recognition of the importance in the aged of the knee joint for prosthetic ambulation the ratio has been reversed and now 80% of ischaemic amputations are performed below the knee with better diagnostic procedures. More procedures are being done at the ankle and foot level (Wagner, 1977, 1978).

All correspondence to be addressed to Dr. M. E. Siegel, University of Southern California School of Medicine, Los Angeles County USC Medical Center, Rancho Los Amigos Hospital, Downey, California, 90242, USA.

The two diagnostic questions facing the team caring for a patient with an ulcer in a dysvascular limb are:

1. If ablation is necessary at what level will a surgical procedure heal?
At Rancho Los Amigos Hospital the ischaemic index measured with Doppler ultrasound has provided a reliable indicator in the 87% + range (Wagner, 1977, 1978). Further studies of nutritive skin flow are now being carried out with intravenous fluorescein measured with a fibreoptic dermofluorometer.

2. Can the patient heal the ulcer and avoid ablation?
If the ulcer can be healed with local means such as Povidone Iodine, walking casts, or with minor local procedures the patient has been saved the major disability of an amputation.

To determine healing potentials in patients with ulcers in an ischaemic limb, peripheral vascular perfusion was measured with Thallium 201 administered intravenously. It has been shown that in the heart, skin, and skeletal muscle Thallium 201 distribution represents the fraction of cardiac output to that tissue and is thus related to regional blood flow (Strauss et al, 1975, 1977).

Invasive studies with Tc-99m-labeled microspheres administered intra-arterially showed a significant relationship between the ability to develop an inflammatory response with its associated hyperemia and the ability to heal an ulcer (Sieqel et al, 1975). Because of the intra-arterial invasive nature of the test it has not been accepted by primary physicians. The same response appears to be measureable with intravenously administered Thallium 201.

Materials and methods
Ten diabetic and three non-diabetic patients were selected who had non-infected ulcers on the

foot, ankle, anterior skin or calf. The patients had not had previous ulcers and there was no radiographic evidence of osteomyelitis or soft tissue gas. At a resting state 1.5 mCu of Thallium 201 were given intravenously. Point counting for 60 seconds was performed 5 minutes after injection directly over the ulcer and at 3 points 2.5 cm. from the edge of the ulcer over normal appearing tissue. A 2.54 cm × 1.27 cm pinhole-collimated scintillation detector was used and the output fed to a pulse height analyzer with digital readout. Healing ulcers produced a readout of 15—20,000 counts per minute, but with non-healing ulcers the counts would go below 1000 per minute. The counts per unit area in the ulcer were then divided by the counts per unit area in the surrounding tissue. This ratio was used as an index of the relative hyperemia of the ischaemic ulcer.

Results

Of the 13 patients 10 were diabetics treated with insulin or oral hypoglycemic agents. Six of these healed, four did not and required amputation or excisional foot surgery. Two of the three non-diabetic patients healed, one required amputation. A ratio or index of 1.5 is taken as the minimum hyperemic response necessary for healing. Seven of the patients had an index over 1.5 and all healed. Six of the patients had an index less than 1.5 and only one of these healed. The mean relative hyperemia of the healed patients is 2.8 ± 0.5, and of those who did not heal is 0.9 ± 0.6. The range of values was from 0.2 to 4.2.

Discussion

Criteria for prediction of healing of ischaemic ulcers may expedite a needed amputation or avoid an unnecessary one. The presence of a relative hyperemia greater than 1.5 was shown to have a significant relationship to healing of such ulcers and thus a predictive value. Intravenously administered Thallium 201 has been shown to be a suitable means for measuring this hyperemia.

$$\text{Adequate relative hyperemia} = \frac{\text{activity per unit area ulcer}}{\text{activity per unit area of surrounding tissue}} > = 1.5$$

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Prediction of leg viabililty and amputation level by fluorescein uptake

D. SILVERMAN and F. W. WAGNER, Jr.*

*Department of Anaesthesia and Surgery, University of Pennsylvania,
Rancho Los Amigos Hospital, California.*

Abstract

There is a continuous search for more reliable, locally non-invasive tests for prediction of leg viability and for the selection of amputation levels in dysvascular lower limbs. Refinement of the dermofluorometer by addition of a shielded probe and fibreoptic bundles has reduced the bulk of the instrument and permitted rapid testing. Excitation light is carried to the tissues and emitted fluoresence is returned to a photo multiplier. The Index of Fluorescein Uptake is 20–30 units in control areas. Healing is constant above 15 units, inconstant from 5 to 15 units, and absent below 5 units. Reliability has been virtually 10% in preliminary tests.

Introduction

Tissue fluorescence following intravenous injection of sodium fluorescein has been used for many years as a visual indicator of capillary blood flow. It has been used in limbs compromised by peripheral vascular disease and in other tissues whose viability was compromised by acute and chronic ischaemia (Lange and Boyd, 1942, and 1944; Myers, 1962). The dye is distributed throughout the patent vascular system. It diffuses through the capillary walls to equilibrate with the extracellular fluid. Exposure of skin or tissue surfaces to blue or ultraviolet light produces a yellow-green fluorescence. Hypoperfusion is presumed in absence of fluorescence.

Estimation of the degree of fluorescence by the naked eye is not accurate and means of

All correspondence to be addressed to Dr. D. Silverman, 7th. Floor. Dulles Building. Hospital of University of Pennsylvania, C400 Spruce Street, Philadelphia, PA 19104.

measurement were sought in the early 1940's. Lange and Krewer reported the dermofluorometer in 1943. Unfortunately the equipment was cumbersome and was not well accepted as a clinical instrument. Modifications and adaptations of the basic concepts have aided in the production of an instrument that separates the bulk of the equipment from the patient. A relatively small shielded probe is used in a normally lighted room. Sterilization of the probe shield permits use of the instrument during surgery.

The fibreoptic dermofluorometer has been developed by Silverman et al, (1980) and the Johnson Research Foundation. The present perfusion fluorometer is manufactured by Diversatronics, Inc., Broomall, Pennsylvania, U.S.A.

Action of the perfusion dermofluorometer

Incandescent light passes through an excitation filter which selectively transmits wavelengths between 450 and 500 nanometers, within the range of maximal excitation of fluorescein in vivo (Delori et al, 1978). This light passes along fibreoptic pathways to the probe which is held on the tissues being tested. The probe also contains fibreoptic bundles which carry the emitted fluorescence plus reflected excitation light back to the instrument. Both fluorescent emissions and reflected excitation light pass through a selective filter before reaching the photo multiplier tube. This filter passes wavelengths between 530 and 660 nanometers. With such selective transmission there is minimal overlap and a resultant high signal to noise ratio. There are two photo multiplier tubes which allow for simultaneous

measurements of experimental and control areas. The emitted fluorescence is quantified by the photo multiplier tube and is read as DF (dye fluorescence) on an arbitary scale.

Tissue uptake of fluorescein appears to be a multiexponential function which can be empirically converted to a "straight line" by graphing "DF readings vs. log time." The slope of this line provides an index of fluorescein uptake (IFU).

Control areas, e.g., forehead, abdomen, and upper limbs, have indices between 20 and 30 units after intravenous injection of fluorescein at 4 mg/kg. All regions with an index greater than 15 remained viable and were able to heal an amputation when performed at that level. In areas where the IFU was below 5 units healing did not occur. Healing was inconsistent in transitional zones with the IFU between 5 and 15 units.

Preliminary studies at Veterans Administration Medical Center, Philadelphia, Pennsylvania, were conducted on laboratory animals (Wagner 1979). There appeared to be a high correlation with tissue viability and tissue fluorescence. Further studies were performed on 9 human subjects with difficult lower limb problems secondary to decreased circulation. Fluorometric studies were contrasted with clinical findings, skin temperature, pulses, pulse volume recordings, ankle/brachial Doppler pressure measurements, and angiography. Fluorometry was 100% accurate; the other tests combined were accurate in 44% of the cases (Table 1). Treatment was based on the "standard tests".

Approximately 30 cases have been studied in a prospective randomized study designed to run two years. Fluorometry has shown a reliability over 95%. At Rancho Los Amigos Hospital a similar study is in progress. Prediction of healing

of leg and foot lesions and selection of amputation level are at a 100% level on the first 11 cases.

A sample protocol outlines the steps for a patient with peripheral vascular disease. The tests are performed in a temperature regulated area.

A. Safety precautions
1. Well running intravenous line.
2. Blood pressure and cardiac monitoring available.
3. Resuscitative personnel and equipment available (highly unlikely to be needed).
4. A physician administers the fluorescein.

B. Grid pattern
1. The anterior aspect of each leg is marked at 5 cm intervals starting at the inguinal ligament. The leg is marked at 2 cm intervals in the areas where amputations are most likely to be performed, e.g. at above-knee, through-knee, below-knee, and Syme levels. In addition, the foot is marked at 2 cm levels on dorsal and plantar surfaces and readings are taken on dorsal and plantar aspects of the toes.
2. Adjustments in the grid pattern can be made before and during the study. Landmarks are recorded on a patient drawing and on the computer program if a computer is used.
3. Control areas are identified on abdomen, forehead, and upper limbs.

C. Pre-injection measurements
1. Temperature reading every third interval.
2. Background readings on both sides of each dot are generally quite low and are subtracted from post-injection readings.

D. Injection of fluorescein
1. Rapid injection through well-running intravenous line.

Table 1. "Standard test" treatment and Fluorometry predictions compared in 9 patients.

	Diagnosis	Treatment based on "standard tests"	Fluorometry prediction	Clinical outcome
1.	Gangrene of toe	Transmetatarsal amp.	Not heal	Not healed
2.	Failed transmet. #1	BK amp.	Heal	Healed
3.	Gangrene of toe	Transmetatarsal amp.	Not heal	Not healed
4.	Failed transmet. #3	BK amp.	Heal	Healed
5.	Infected foot	Medical prescription	Fail	Failed
6.	Extension of foot infection #5	BK amp.	Heal	Healed
7.	Infected AK amp.	Possible disarticulation	Surgery not necessary	Healed
8.	Foot ulcer	Medical prescription	Heal	Healed
9.	Ulcer of BK amp.	Medical prescription	Heal	Healed

2. At 45 seconds measurement is started-probe is moved to all points (1 second/point).
3. Points are measured sequentially for 20 minutes.
4. A computer aids markedly in assembling data. The reading and time for each data point are recorded, the time course of fluorometer readings are graphed and analysed for each point, and at 20 minutes ratios between the test sites and control areas can be provided. Areas showing critical changes can be further subdivided, further readings and ratios obtained.

E. Post examination
1. Patient observed for one hour post-injection.
2. The patient and those caring for him will be instructed in possible changes in skin and urine colour.

F. Statistical analysis
1. Patients will be randomly assigned to control or treatment groups. In the control group the surgeon will not be shown the perfusion results. Amputation will be carried out at the level determined by the hospitals "standard" means of assessment (Wagner, 1979).

   In the treatment group amputation will be performed at the level determined by the test showing the greatest amount of limb salvage. Successes and failures will be analysed by standard statistical methods.

G. Risks

Most articles report virtually no complications. However, a recent review of the literature reports two cardiac arrests and three fatal reactions (Buchanan and Levine, 1982). The same authors report a study on 38 flap procedures in 29 patients over a ten year period. An immediate blood pressure drop of more than 20 mmHg was noted on nine occasions. Pressure returned to base line with supportive measures in six patients, but ephedrine was felt to be necessary on three occasions.

The only side effect seen so far in our patients has been mild nausea.

Summary

Tissue fluorescence has been used to aid in determining nutritive blood flow. Quantification of fluorescence by the naked eye has not been accurate. Previous instruments to measure fluorescein dynamics were not acceptable for clinical use due to cumbersome size.

A new fibreoptic perfusion fluorometer has been developed that contains the basic elements of earlier instruments but removes the bulky components from the patient. The probe is placed on the area to be examined after fluorescein injection and a reading is obtained in one second.

Preliminary studies in animals and in humans show that ultimate viability of tissue can be predicted and amputation level selected with great reliability.

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Operative technique in knee disarticulation

K. JANSEN and J. STEEN JENSEN

Department of Orthopaedic Surgery T–2, Gentofte Hospital, Copenhagen.

Abstract

The operative technique is described in detail. Pitfalls are emphasized and comparisons made with other techniques.

Introduction

Interest in the through-knee (TK) amputation was created during a visit to the headquarters of Col. Maurice Fletcher at the Walter Reed Hospital in Washington DC in 1953, where they were considering a combination with quadricepscine-plasty.

The traditional Spittler approach with a large anterior flap was used in Copenhagen until Kjølbye (1970) suggested the use of two side flaps. In arteriosclerotics this technique provided flaps with a safer blood supply. This technique has been routinely used in Gentofte.

Operative technique

The surgical technique is a minor procedure as little soft tissue is divided. The level is determined essentially by determination of the blood flow, measured by the Holstein technique (Holstein and Lassen 1973) and of course by the clinical findings such as skin or bone disorder or a severe knee joint contracture.

Primarily a circular skin incision (Fig. 1) and preparation of two square flaps are performed. The final trimming of the skin is delayed until wound closure. The patellar tendon, the collateral ligaments and the tendon of the hamstrings are detached. After a broad transverse capsulotomy the joint is widely exposed. Next the cruciate ligaments are divided

at their distal attachments. After division of the posterior capsule, the gastrocnemius are divided 2 cm below joint level in order not to sacrifice the superior genicular artery.

The vessels are ligated at joint level and the tibial and peroneal nerves are isolated, pulled down gently, ligated and divided. The ligature of the nerves in amputation surgery serves to create a circumscribed neuroma, which is easier to identify and handle than dendritic neuromas in cases of re-operation for pain caused by post-amputation neuroma.

After removal of the menisci, the patellar tendon and the hamstring tendons are stitched to the cruciate ligaments and the capsular brim. Proper tension of the sutures is emphasized. The correct placement of the knee cap is of utmost importance as the apex of the patella must never reach below the condylar level (Fig. 2). Ideal positioning leads to a triangular stump end consisting of the two condyles and the apex patellae. The final shaping of the gastrocnemius heads is undertaken to cover the posterior part of the joint cartilage.

An intra-articular suction drain is inserted through a separate incision and the wound is sutured after trimming the skin flaps. Subcutaneous interrupted sutures are
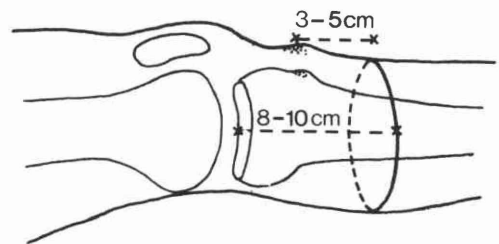

Fig. 1. Circular incision 3–5 cm below tibial tuberosity or 8–10 cm below level of knee joint.

All correspondence to be addressed to Dr. J. Steen Jensen, Department of Orthopaedic Surgery U, Rigshospitalet, University of Copenhagen, DK–2100 Copenhagen Ø, Denmark.
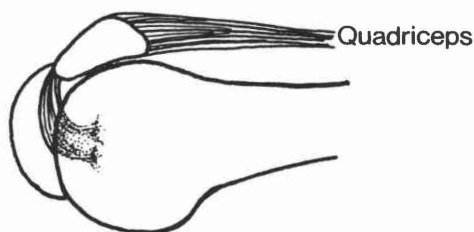
Fig. 2. Lig. patellae sutured to cruciates bringing the apex of the patella level with the femoral condyles.

recommended using an absorbable material such as polyglycol acid. Interrupted atraumatic nylon sutures, or other monofile non-absorbable materials, are recommended with close adaptation of the skin edges. The wound has to be treated as all other operation wounds. There is no reason for using few, deep interrupted sutures, as the destiny of the wound is dependent on the blood supply.

In vascular cases the skin sutures are removed after three weeks as a rule, but after normal healing in others. The postoperative dressing consists of an elastic bandage or a plaster of Paris, which has to be changed after one week to inspect the wound

Discussion

The predominant disadvantage of the TK amputation is the cosmesis, as the protruding knee joint of the prosthesis is less acceptable, especially in women.

The advantages, however, greatly exceed the cosmetic problem and are listed in Table 1.

The majority of the advantages are related to the prosthetic fitting procedures as will be described in other papers of this issue. It is, however, well known that weight-bearing stumps lead to better comfort and improved prosthetic fitting. The architecture of the TK stump provides a triangular stump profile thus distributing the pressure at the stump end over a larger area. This reduces the risk of breakdown of the skin over the stump end. In our series of more than 70 TK amputations no late surgery for skin problems was required.

Other techniques have been introduced over

Table 1. Advantages of through-knee amputations.

weight bearing stump
triangular stump profile
strong lever arm
perfect muscle balance
minor surgical trauma

the years, such as the Gritti-Stokes procedure with transplantation of the patella to the resected condular area. The stump end is thus created by the patella and consequently the pressure is distributed over a smaller area.

Another advantage is the perfect muscle balance of the hip and thigh muscles, as no muscular attachment is removed significantly from its original position. This facilitates prosthetic walking, as the quadriceps is not weakened and the hamstrings can still act as hip extensors.

The triangular shape of the bulbous stump also secures the rotational stability of the well fitted prosthesis. This is in contrast to the Mazet procedure, where the femoral condyles are shaped by bone resection for cosmetic reasons alone.

The major surgical advantage of the knee disarticulation is the minor surgical trauma. No bone surgery is performed and synovectomy is not attempted. As no large bleeding areas are left, the postoperative oozing and haematoma formation is reduced. In contrast to the Spittler procedure the technique utilizing side flaps places the scar in the intercondylar area, which is relieved of pressure.

In using the described procedure a few technical problems might be considered. In cases of severe knee contracture the dorsal skin incision should be placed fairly distally in order to facilitate skin closure and the hamstring attachments might be sacrificed. The TK amputation is, however, also superior to the AK amputation in these cases if technically possible. In some cases wound closure might be difficult because of skin tension. This is especially a problem over the prominent medial femoral condyle. In such cases minor resection of the femoral condyle should be undertaken as a pressure necrosis of the skin might otherwise occur leading to secondary AK amputation. The last problem to be mentioned is the postoperatively appearing synovial fistula, which occurred in 6 per cent (4/71) of our series (Jensen et al, 1982). The fistulas were located in the wound between the condyles and always dried out without further surgical treatment within a few months. The appearance of synovial fistula did not postpone the prosthetic fitting as no pressure occurs in this area.

In conclusion, the surgical technique utilizing side flaps and positioning the apex patella level

with the condyles is recommended for TK amputations as the surgical trauma is minimal, the procedure fast and safe and the stump advantageous for prosthetic fitting.

Note

This contribution is based on lecture notes and papers found in Knud Jansen's office after his death on 1 August 1982. The style and choice of words are in accordance with his presentations as are the opinions expressed.

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The postoperative environment of the amputation stump

Postoperative wound dressing after through-knee amputation

G. MURDOCH

Department of Orthopaedic and Traumatic Surgery, University of Dundee, Scotland.

Abstract

This paper reviews different types of treatment of the amputation stump. Following an examination of the historical development there are sections on bandaging, semi-rigid dressings, rigid cast dressing and controlled environment treatment. The merits and demerits of each type of treatment are discussed.

Introduction

The considerations which have to be addressed in discussing a dressing for any terminal wound are:

1. Protection from bacterial infection.
2. Containment or reduction of oedema whether present preoperatively or as part of the tissue response to operative trauma.
3. The protection of the stump from physical trauma as exposed in the rehabilitation of the patient, and
4. Possibly, to provide attachment of prosthetic devices to permit early walking.

Historical

These factors have operated over the thousands of years during which amputations have been performed though it is doubtful if the objectives were so clearly defined, albeit intuitively encompassed, in the solution. For many centuries an additional objective was to ensure stoppage of bleeding and many solutions for this problem have been employed. These included amputation below, at, or just above the level of gangrene as employed by (Celsus *circa* 25 AD), and tourniquets of various kinds until eventually Paré electively ligatured vessels

(Taylor, 1933). Cautery was also widely used but the practice, as used in the Peliponnesian wars, of applying small buckets of tar to the end of the stump combined several objectives—cautery for haemostasis, protection from infection, a fixed volume for the stump thus containing oedema, and it is believed, in some cases provision for weight-bearing by the addition of a peg attachment.

From that time on a variety of dressings were employed including lint and sea sponges. Gersdoff in 1517, as described G. Taylor (1933) advocated rabbit fur and egg white and several surgeons employed a pig's bladder. This particular method is interesting as it might cover all but one of the considerations listed above.

Bandaging of stumps has been employed for many hundreds of years. The continued use of bandages as the weeks passed following amputation was primarily directed towards producing a conical shape in the stump to meet the demands of the then conically shaped sockets. In more recent times with advancing technology a variety of wound dressings, both occlusive and porous have been produced. Equally there have been advances in bandage design and in the use of plaster of Paris. In the past fifteen years devices have been developed seeking to find more fundamental solutions.

Present methods and techniques

Today bandaging is still employed as a means of covering the stump following operation. The bandages may be non-elastic, elastic or have properties akin to the traditional Unna's paste bandage producing a semi-rigid structure. Rigid dressings in the form of plaster of Paris casts are used widely and in more recent time a controlled environment treatment technique has found favour in some units.

Bandaging

The problem inherent in any bandaging technique is the danger of creating an adverse pressure gradient. Very often that adverse pressure gradient is a direct result of the need to ensure that the bandage does not slip. Voluminous padding applied between the bandage and stump may avoid this danger but the bandages still tend to work loose and appear to offer nothing more than a cover for the wound.

There can be no doubt that a properly applied bandage is beneficial; provided that the bandage pressure does not exceed intravascular hydrostatic pressure, bandaging will limit the formation of oedema but will not increase the vascular resistance to the detriment of blood flow. Intracapillary pressure in the recumbent position is of the order of 15–20 mm Hg but varies with posture (Chant, 1972) thus requiring a bandage which provides graded pressure as devised by Wood (1968). Spiro et al, (1970), Husni et al, (1968) and Johnson (1972) all advocated pressures in the 10–20 mm Hg range as being maximal. Isherwood et al, (1975) in comparing the efficacy of three different types of stump bandages, studied the pressures produced by both skilled and unskilled bandagers. Not surprisingly the skilled bandagers performed better and the results varied with different bandages, but the striking result was the fact that pressures as high as 140 mm Hg were produced even by skilled bandagers. In the light of that evidence there are clear grounds for careful consideration of the implications of the use of a bandage.

Semi-rigid "dressings"

Ghiulamila described this type of dressing as applied to an amputation stump in 1972 and has remained an enthusiastic protagonist since then at different levels of amputation, including the through-knee amputation. Essentially he uses a modified Unna's paste bandage with the classic ingredients of zinc oxide, glycerine and gelatin. Once applied this bandage forms a semi-rigid dressing which, while flexible, is inextensible in terms of volume. It adheres well to the skin and makes for a stable situation with respect to the wound.

Lippman and McMaster (1972) in a well considered contribution cover the theoretical and practical aspects of applying a Unna's paste bandage. As with other bandages considerable skill is required in its application but once the pressure gradient is achieved it tends to be sustained, they point out that no more than 1 cm H_2O pressure is required to dissipate oedema.

The air splint

This is a device designed as an emergency splint for stabilizing fractures. It was first recommended as an immediate post-operative dressing by Little (1970) over rolled cotton wool and bandages and inflated to a pressure of 25 mm Hg. Sher (1974) reported on a similar technique; he used a towel wrapped around the thigh to absorb moisture and prevent maceration of the skin.

Hard foam dressing

This technique employs a stocking incorporating a zip (Blömer, 1978). A polyurethane foam mix within the stocking forms around the stump; it can be used immediately following surgery.

Rigid cast dressing

Coincident with the concept of immediate post-operative fitting of prostheses there was clearly a need to apply a rigid wound "dressing" as an integral part of the technique. Berlemont (1961) first described the technique and through the experiences of Weiss (1966) Burgess and Romano (1968) and many others the technique has become widespread. Many have abandoned the early prosthetic fitting for a variety of reasons, but the rigid cast dressing remains in use. There are many varieties but that decribed by Romano and Burgess is well received. A silicone impregnated wound dressing is applied and is overlaid with a quantity of fluffed gauze; and elasticated sock is then pulled over the stump. Felt pads in strategic positions are applied and elasticated plaster of Paris bandages are laid on without tension ensuring that the cast conforms well to the shape of the stump. As the plaster hardens it is carefully moulded around the femoral condyles. Especial care is required over the posterior aspect of the femoral condyles in the through-knee amputation.

Mooney et al, (1971) compared the use of the rigid cast with soft dressings in a series of 182 below-knee amputations performed on diabetic patients. In this well controlled study it appeared that the rigid cast was a positive factor in achieving a healthy wound. Baker et al, (1977) conducted a similar study on 51 patients with below-knee amputations and found that neither

wound dressing technique proved superior, with healing rates almost indentical.

Controlled environment treatment

This technique and the associated device were developed at Roehampton, England by Redhead (1973) and Redhead and Snowdon (1978). Essentially the stump without dressing is placed inside a sterile bag or sterishield which has a proximal internal apron which prevents ingress from air outside and permits sterile air at a known temperature and pressure to be pumped in. The motor, pump and filter are conveniently housed within a control consul which permits the clinician to select the appropriate pressures (cycled if need be) and temperature. Troup (1980) recorded an experience with use of the device in 100 patients and, while noting the practical difficulties of setting up a randomized controlled trial, believed the results were better than with rigid dressings.

Discussion

The amputating surgeon, sensitive to the problems that may arise, will choose a method of stump environment which will be least likely to harm his patient and, if possible, provide some control of oedema. In the Northern hemisphere, where the great majority of amputations are performed for vascular disease, where he seeks to perform the amputations at the lowest possible level and where skin perfusion pressures are marginal, the decision will depend largely on his competence in bandaging, whether it be a soft bandage, a Unna's paste bandge or a plaster of Paris bandage. While Baker et al, (1977), showed that wound healing was no different with a soft or plaster dressing, they did note that the rehabilitation of patients with wounds that healed primarily with plaster started sooner. They noted that patients with soft dressings almost uniformly had some oedema despite wrapping with an elastic bandage and the persistence of this oedema postponed the beginning of walking training. For these reasons they normally used a plaster dressing. It seems therefore that if soft dressings are to be used and the stump is bandaged over these soft dressings in such a way as to avoid an adverse pressure gradient, then the penalty must be poor dissipation of oedema. If the surgeon is accustomed to handling plaster of Paris then he will probably elect to use a rigid cast dressing in the knowledge that it provides an effective barrier to infection, permits the patient to move about freely in the course of his rehabilitation without risk of damage to the stump and has a good record in so far as control of oedema is concerned. At the same time, if much oedema is present at the time of amputation, the fit of the plaster cast on the stump will be lost with all the dangers to bony prominences as a result of the incongruity.

Where oedema is present and particularly if through-and-through drains are employed the surgeon may elect to use a Unna's paste bandage, as it is readily replaced and amenable to removal of drains but affords less protection for the stump. For those who are concerned to avoid adverse pressure gradients and are not accustomed to using plaster of Paris then an air splint or hard foam dressing would appear to offer a reasonable alternative. The tendency to sweating inside the air splint must be a disadvantage because of its possible influence on infection.

The advantages of controlled environment treatment are unequivocal as no skill is required in its application, there is control of pressure and temperature, sterility is maintained and the wound can be observed throughout the treatment. It would seem to have a marked advantage in patients where oedema is a feature. However the apparatus is expensive, the patient is much less mobile and this can lead to distressing frustration and it can prove to be a environmental hazard for staff.

Finally it should be noted that there is no need to confine oneself completely to one technique or another. For example, in the diabetic patient with marked oedema it might be wise to use controlled environment treatment for a few days until the oedema is controlled and thereafter to apply a rigid cast to permit more rapid rehabilitation of the patient. One's main concern must be to avoid an adverse pressure gradient.

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Physiotherapy following through-knee amputation

G. MENSCH

Physiotherapy Department, Henderson General Hospital, Hamilton, Ontario.

Abstract

Physiotherapeutic treatment considerations specific to the through-knee amputee are presented. Treatment is determined by the assessment findings. The physiotherapy programme includes post-operative exercises, early weight-bearing, bed to chair transfers, bandaging techniques, the counteracting of contractures and gait training. Physiotherapy is a vital part of the rehabilitation of through-knee amputees. Principles of treatment are based on normal human locomotion, the individual patient's health status, biomechanical changes and expected stump functions. The through-knee stump is generally problem free, functional and end-bearing, allowing for a high rehabilitation rate in independent ambulation. It is therefore well suited for the geriatric amputee.

Introduction

The physiotherapist will see fewer patients with knee disarticulation compared to patients with below-knee (BK) and above-knee (AK) amputations during lower limb rehabilitation. Although all recent lower limb amputation levels have common functional treatment goals such as:

healing of the surgical suture,

stump maturation prior to definitive prosthetic fitting,

gait training,

each stump level will present different ambulation and prosthetic fitting problems. These have to be dealt with on an individual basis. Therefore, the treatment planning for a recent through-knee (TK) amputee has to be directly related to the amputee's physiological, functional and mechanical losses.

All correspondence to be addressed to Ms. G. Mensch, Chief Physical Therapist, Physiotherapy Department, Henderson General Hospital, 711 Concession Street, Hamilton, Ontario, Canada L8V 1C3.

Assessment

An assessment for physiotherapy treatment planning includes the following considerations (Holliday, 1981; Mensch and Ellis, 1982).

1. *Reason or reasons for surgery*
   These will help to indicate the expected activity tolerance and the rate of treatment progression.
2. *General health of the patient*
   The amputee's energy output depends on his general medical condition which will also influence the setting of the treatment goals, e.g. independent locomotion, assistive devices necessary, aiming toward wheelchair independence.
3. *Stump condition*
   This evaluation has to be specific. Test and observe stump length and shape, muscle strength, range of motion of the hip joint, healing of the surgical suture, stump oedema, skin sensation, the presence of pain and response to weight bearing. All stump functions and conditions will affect leverage control and gait cycle performance. It will also indicate the ability of the stump to tolerate stresses of weight bearing and skin friction.
4. *Proprioception and balance*
   Prior to amputation surgery, the patient's gait was automatic. However, the loss of the shin and foot will contribute to an initial proprioceptive disturbance and lack of co-ordinated muscle action, which will affect balance.
5. *Condition of the remaining leg*
   The remaining leg will become the dominant limb. It will hold the body weight, balance while donning the prosthesis, pivot, control stairwalking, initiate standing up and sitting down, control driving, etc. When signs of intermittent claudication are present, standing activities are restricted.

6. *Pre-amputation ambulation*

An investigation into the ambulation pattern prior to amputation surgery will determine the post-amputation level of ambulation which may be achieved.

The assessment findings will help to establish realistic treatment goals.

Through-knee amputations—specific characteristics

Ambulating a patient with a knee disarticulation is closely related to AK gait training. Similarities include the loss of knee function and learning prosthetic knee control. However, the knee disarticulation stump has several distinct functional, physiological and mechanical advantages because during surgery, bone and muscle tissues remain intact (Harris, 1970; Baumgartner, 1979; Kostuik, 1981; Murray and Fisher, 1982).

Factors aiding ambulation

1. Total end-bearing through the femur contributes to stump-socket comfort.
2. Balanced muscular control of all thigh muscles allows for co-ordinated stump movement.
3. End-bearing and stump length provide rotational stability between stump and socket.
4. Proprioceptive awareness is better as muscle tissues have not been surgically disturbed. This results in quicker readjustment to balance and stump position sense.
5. The stump shape permits a relatively easy socket suspension by contouring the socket wall above the femoral condyles.

Because of stump length, end-bearing, balance muscle control and socket comfort, the prosthesis is comparatively easy to manage.

Disadvantages specific to through-knee amputations

1. The actual stump length presents a problem during prosthetic fitting (Bell, 1970) as the placement of the mechanical knee axis falls below its anatomical position. This results in increased thigh length and a shorter shin section.
2. The thigh-shin imbalance affects the biomechanics of the gait cycle.
3. The cosmetic appearance of the prosthesis is disproportionate.

Physiotherapy treatment

Following surgery, the amputee attempts to adapt his stump motions and his locomotor pattern by *what he feels*. He perceives by touch (Mensch and Ellis, 1982). Therefore, correct guidance is indicated immediately. Sensory feedback can be provided by using stump-hand contact. The therapist assists, resists and guides the stump manually through the expected joint ranges helping the amputee experience stump control. Manual feedback also stimulates proprioception; it gives the amputee an awareness of the intensity and/or speed with which he needs to control his stump motions. Manual guidance encourages the re-establishment of automatic muscle control in preparation for prosthetic ambulation.

Post-operative phase
(for the casting technique and the post-operative soft dressing procedure.)

Phantom sensation

This is the phenomenon which makes the amputee feel complete (Koerner, 1969; Holliday, 1981; Murray and Fisher, 1982). The awareness of feeling and moving the amputated limb can be useful during treatment. The sensation is utilized to practice bilateral leg exercises which will stimulate stump proprioception and help in establishing a controlled and more automatic gait pattern.

Exercises

In preparation for ambulation, isometric exercises are initially practiced. *Extension* is *emphasized* because:

1. The trunk extensors hold the body erect.
2. Stump extension stablizes the artificial knee on stance.
3. Hip extension places the centre of gravity through the hips and permits standing with ease.

Flexion exercises are *secondary* because:

1. The amputee practices flexion routinely when sitting up and getting in and out of bed, chairs, etc.
2. He uses his stump actively as a balancing lever (in a hip flexion position) when standing on one leg and when attempting to walk.

Early weight-bearing

In TK amputations, early weight-bearing is practiced (Holden, 1981; Mensch and Ellis, 1982). This is done by providing manual distal pressure, either over the post-operative cast or

over the soft dressing. The amount of gentle intermittent compression that can be tolerated is judged by the amputee's comfort. Weight-bearing practice can be continued regularly during the day by the amputee himself by using a sling over the stump end to provide distal end bearing pressure (Fig. 1).

Fig. 1. Controlled, graduated weight-bearing as well as stump desensitization can be practiced using the sling or towel technique.

Graduated compression gives the TK amputee a feeling of comfort and support. This feeling is experienced because the femur is intact. Distal pressure:

1. Reduces stump swelling.
2. Aids in stump desensitization.
3. Eases the stump throbbing sensation which may be experienced when the stump is initially in a dependent position.

Weight-bearing is gradually increased by allowing partial body weight-bearing in the gait-training unit (Mench and Ellis, 1982). Weight-bearing progression is observed when the amputee can decrease the amount of weight placed on the ambulatory aids, indicating an increase in weight-bearing through the prosthesis.

Transfers

Transfers require balance, muscle co-ordination, strength and abdominal control (Holliday, 1981). Supervision or assistance must be given initially to assure that the amputee practices safe transfer techniques.

Bed to wheelchair

1. The shoe is placed on the remaining foot prior to transfer.
2. The wheelchair is positioned next to the bed on the non-amputated side.
3. Secure wheelchair brakes.
4. Assist the amputee into sitting up by using thigh stabilization and the hand-pull technique (Fig. 2).
5. The remaining foot is placed on the ground.
6. Pause and encourage deep breathing to overcome possible postural hypotension.

Fig. 2. Thigh stabilization and the hand-pull method assist the geriatric amputee in getting to the sitting position.

7. The patient pushes on his hands using triceps and abdominal muscles to bring his trunk weight forward and attempts to stand. He then reaches for the wheelchair armrests and pivots.
8. The therapist stands on the amputated side at a 45° angle holding the amputee's hips and guiding the transfer. The therapist's position permits knee counter-pressure against the patient's knee providing stability in case the stance leg should buckle (Fig. 3).
9. Using both hands supported on the arm rests, the amputee then sits down.
10. If applicable, the base section is then attached to the non-removable cast or the training unit is donned. Early ambulation can begin.

Only in recent post-surgical BK amputations will the base unit be attached to the cast *prior* to the transfer procedure. This is done because the knee is cast in extension and supporting the base unit eliminates lever pressure over the anterior aspect of the stump end (Mensch and Ellis, 1982); in TK amputations, this is not necessary.

Sitting to standing with temporary prosthesis

1. Sit forward in chair.
2. Extend prosthetic knee with heel on the floor.
3. Bend the sound knee more than 90°.
4. Shift trunk weight forward placing body weight over thighs.
5. Push on arm rests while coming to a standing position with weight supported on the remaining leg as well as the ambulatory aid.
6. Draw prosthesis underneath trunk.
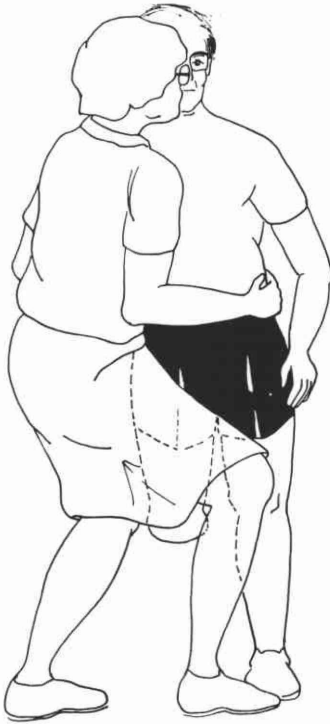7. Place feet parallel and get the feeling of a balanced stance.

Fig. 3. The therapist's position controls the transfer counteracting a possible knee buckling of the amputee's stance leg.

Immediately post-surgically, when the stump is in a dependent position, a throbbing or pulsating sensation is experienced. This is normal and will subside within a short period of time.

Oedema

Stump oedema is common following amputation surgery and can affect the rate of healing of the suture line (Menzies and Newham, 1978), the TK amputation level is no exception. However, the severity of the oedema is usually not as marked as in AK stumps. Reduction in swelling is necessary to help the stump stabilize. Only a mature stump can act as a controlled lever and can be provided with a snug prosthetic socket fit (Fig. 4).

Stump oedema will decrease by walking regularly with a gait training unit. The alternating motions of swing and stance allow the stump muscles to contract and relax against the socket walls thus decreasing the stump circumference. The TK stump has to be reduced in girth to fully utilize the femoral condyles as

socket suspension. A gradual reduction in stump volume can also be achieved by correct bandaging techniques.

Bandaging

Bandaging, if supervised and correctly applied, is an economical and effective stump shrinking and shaping method (Holliday, 1981; Mensch and Ellis, 1982). Fluid reduction is achieved by providing distal bandage pressure which is gradually decreased as the bandage continues proximally. A bandage should always feel comfortable giving firm support to the stump. A comparison can be made to a patient following abdominal surgery who will hold his hands over the suture to give comforting support when coughing. The stump bandage should provide the same support equalizing the internal and external pressures on the stump. Never apply a bandage in tight circular turns as this may restrict circulation and can have adverse effects on the stump.

Some clinicians are opposed to bandaging (Brady, 1982) claiming that the amount of bandage tension cannot be controlled. This is of particular concern in the vascular patient. These negative clinical findings reinforce the
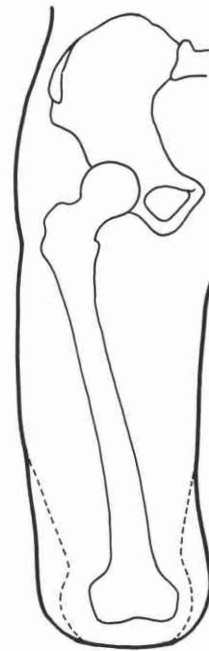

Fig. 4. Oedema reduction allows for socket suspension above the condyles.

importance of being selective in *all* treatment modalities used to reduce stump oedema. However, it can be argued that other rehabilitation treatment methods cause stump tissue stress of greater intensity than bandaging, e.g. during weight bearing. Maximal compression is experienced when the stump tissues contract during stance against the socket walls and again the amount of compression cannot be controlled or measured. However careful stump observations are made and the stump eventually matures so that it can act as a lever and support weight. Bandaging starts immediately after the post-operative cast is removed. Following a post-operative soft dressing application, bandaging starts' after initial healing of the surgical suture has taken place.

Through-knee bandaging technique

1. If right handed, stand on the right side of the patient.
2. Start the bandage diagonally over the stump end directing the bandage medially. This initial directional turn is important as it later guides the stump towards body midline. (If reversed, the stump would be pulled into abduction.)
3. Proceed in a figure of eight fashion repeating the stump end turns and continue proximally.
4. Extend the bandage across the pelvis anteriorly and around the back.
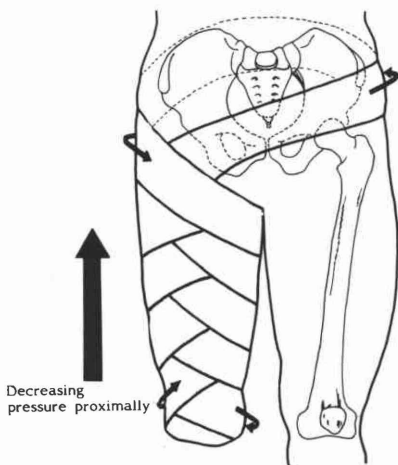

Decreasing pressure proximally

Fig. 5. Distal bandage compression aids in stump shrinkage.

5. The completed pelvic turn is then directed medially high into the groin area covering the adductor region. (Fig. 5). The pelvic turn is repeated and the bandage end secured with safety pins.

Some throbbing stumps will get relief from bandage support. Compression markings seen on a swollen stump when the bandage is removed indicate that the reduction of fluid is successfully being controlled by the bandage application. Do *not* confuse these bandage turn markings (which quickly disappear) with irritated or angry looking skin areas which can be caused or aggravated by compression. Different stumps take different compression tension. The clinical guide to a correct bandage application is the expressed comfort of the amputee. Objective stump girth measurements are recorded weekly to act as a guide since definitive prosthetic fitting can only proceed when measurements stabilize.

The bandage is removed

When the stump pain is biting in nature combined with a sensation of cold or in case of reddish-blue discolouration of the stump skin or venous restriction.

Contractures

Through-knee amputation stumps demonstrate a lesser number of contractures clinically because the surgical procedure leaves the thigh muscles intact. If a hip flexion contracture exists, the gait pattern is affected for several reasons:

1. The iliopsoas muscle is tight.
2. The amputee leans forward on prosthetic stance.
3. The gluteus muscles are overstretched and do not have enough power to hold the prosthesis in extension.

All these factors result in gait deviation and higher energy consumption. Moderate hip flexion contractures can be treated. However, marked hip flexion contractures cause major fitting problems due to the TK stump length (McCollough et al, 1971).

Preventive measures to counteract contractures

Prone lying is important for the TK amputee. The prone position is restful (Holliday, 1981), allows all joints to be in mid-position and provides stump position control without stress by turning the head toward the sound side. Frequent daily prone lying periods are indicated following activity sessions. A firm wheelchair seat supports the pelvis and counteracts a pelvic

drop. A hammock seat permits stump internal rotation and adduction. Sitting on one buttock also can lead to scoliotic compensation. Therefore, equip the chair with a sitting board. A firm mattress during supine rest periods will prevent the pelvis from sagging counteracting hip flexion contractures.

Stretching of hip flexion contracture for TK amputees

1. The amputee lies on his sound side with the leg in flexion. The flexed leg provides a stable side lying position and also flexes the lumbar spine (Mensch and Ellis, 1982).
2. The therapist kneels at buttock level behind the amputee using his/her position to counteract spinal motion. This is done to get a true hip extension stretch and to prevent the joints above from compensating thus reducing the actual stretch on the hip joint.
3. One hand provides counterpressure against the posterior aspect of the hip, while the other hand stretches the stump into hyperextension.

The passive stretch technique is indicated for muscle tissue shortening only. If fixed joint contractures limit joint range, do not attempt to stretch. Stretching is done only within pain-free limits. Producing pain will cause a reflex hip flexion to avoid the painful stimulus of the stretch. Following passive tissue stretching, practice gluteus contractions to encourage active hip extension which will counteract hip flexion. Individuals who demonstrate joint hyper-mobility do not develop contractures while people with pre-existing kyphotic postures are more inclined to develop stump contractures.

Gait practice

Stump placement in the prosthesis must be precise because the socket is constructed to adhere to the anatomical contours of the stump. If the stump is not positioned properly, the pressure distribution will be incorrect causing stump pain and the prosthesis will be malaligned.

The TK amputee *donning* his prosthesis sits forward on a chair.

1. The artificial knee is positioned in extension.
2. The stump is placed into the socket. If the patient wears a double wall socket, the inner soft liner is donned first and then inserted into the outer rigid socket (Baumgartner, 1979).

3. The sound leg stands up.
4. The stump pulls the prosthesis backwards into a stance position.
5. Full weight-bearing is necessary to judge the correct socket fit.
6. Additional suspension, if applicable, is then secured.

Weight shifting and posture control

Prior to walking, the amputee exercises, repeatedly practicing weight shifting and step position exercises (NYU 1975). This is done between the parallel bars in front of a mirror using visual feedback. Heel contact, foot flat and toe off positions provide feedback from the ground which enhances proprioceptive awareness. In this way, the stump also learns to adjust to the weight and the functions of the prosthesis.

The most important gait function based on controlled weight shifting which the TK amputee has to learn, is to initiate hip flexion following toe off (Fig. 6). This movement will accelerate the prosthesis forward into the swing phase. This phase proves difficult to master because of the length of the thigh lever. Careful hip-knee-ankle
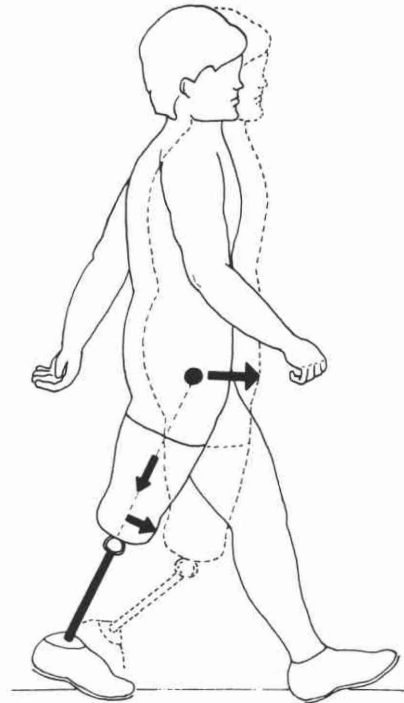

Fig. 6. Learning to initiate prosthetic knee flexion proves difficult for some TK amputees.

alignment can over-compensate when the thigh is longer by providing too much knee stability. The patient feels "glued" to the ground.

Instead of keeping the weight on the prosthesis and dropping the pelvis, allowing the prosthetic knee to flex and accelerate, the amputee will hoist his pelvis eliminating weight bearing and swing his prosthesis forward by either circumducting abducting or by vaulting on the sound side. He will almost walk stiff legged and does not control his prosthesis (Foort, 1979). The position of the prosthetic knee axis is crucial as to how well the amputee can utilize its function and shift weight. Prosthetic heel contact is often achieved by excessive impact in order to secure immediate knee extension (Hughes, 1970). The socket vibrations on prosthetic knee extension, as well as the auditory feedback, will indicate to the amputee that weight can be placed on the prosthesis without the knee collapsing.

Standing balance

This is tested by "pushing" the amputee in various step positions to see how well he will recover from unexpected postural changes.

The TK stump is able to bear weight on its distal end, therefore it serves extremely well in giving the remaining leg total relief during prosthetic stance. In non-weight-bearing stumps, stance on the sound side is increased, thus tiring the remaining leg somewhat more quickly and possibly affecting balance.

The TK amputation should therefore be considered for the elderly who usually lose their leg due to vascular insufficiency. End bearing and the improved proprioception and balance achieved with a TK amputation help the elderly patient to be a prosthetic candidate.

Gait pattern

Each phase of stance and swing is individually practiced, reinforced and corrected. Progression to crutches is indicated when the TK amputee controls heel-strike, foot-flat, mid-stance, heel-off and toe-off rhythmically, and when his sound leg oversteps the prosthesis. An upright posture placing the centre of gravity over the hip joints is stressed (Mensch, 1979) throughout gait practice as it is energy efficient. The therapist teaches posture control by utilizing hand contact to correct the trunk posture, thus providing feedback by touch. Other modalities include mirrors and videotape recording (Netz et al, 1981) for visual feedback and limb load monitors

for audio feedback during gait training. It is also important to practice trunk rotation and alternating arm swing to assist the accelerating and decelerating body motions which are normal in human locomotion but are restricted by ambulatory aids.

If the treatment is aimed towards independent locomotion, *do not* allow the TK amputee, during the early post-operative phase to walk stiff legged by using a pylon, because the amputee tries early on to readjust his locomotion by what his stump perceives.

1. A stiff knee prohibits proprioceptive awareness of the hip extension function and thus deprives the amputee of the feeling of stability on stance.
2. A stiff knee does not allow the swing phase to follow its normal cycle (Fig. 7).
3. A stiff knee encourages gait deviations such as prosthetic circumduction and abduction or vaulting on the sound side.
4. A stiff knee gait is more energy consuming because the natural acceleration and deceleration of the prosthesis cannot take place.
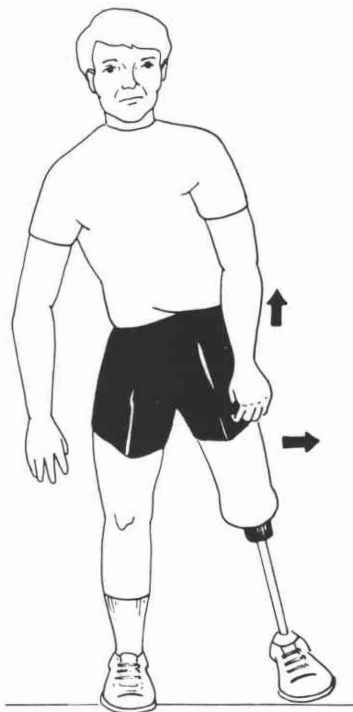

Fig. 7. Walking post-operatively with a stiff knee produces incorrect proprioceptive feedback.

If, however, the assessment indicates that the TK amputee will not be able to walk independently with a free swinging prosthetic knee, then a modified commercial gait device, which can hold the artificial knee position in locked extension, can be prescribed to help the more debilitated person to get about enough to cope with activities of daily living.

Stairwalking

Up: The sound leg proceeds; the prosthesis, held in extension follows (Alexander, 1978).

Down: The prosthesis is placed on the lower step first, held in extension. The sound leg which is able to hold the body weight in a knee flexion position, will follow.

Inclines

Up: The amputee approaches the incline in a sideways position with his sound side facing the uphill slope. The sound leg steps up and the prosthesis follows with the prosthetic knee in extension, stabilizing the position.

Down: The extended prosthesis leads, also in the sideways position, and the sound leg follows.

The sideways position to the line of progression is important to avoid buckling of the prosthetic knee on the incline.

Falling

Falling techniques should be as simple as possible because during the fall, the TK amputee does not have time to think which procedure to use for a forward or a backward fall.

Teach: Let go of the crutches and flex the body.

Reason: Body flexion reduces the impact of a fall. Body extension increases the impact.

Getting Up

Practicing to get up off the floor is important.
1. Flex the sound leg.
2. Extend prosthesis.
3. Roll trunk toward sound side and use momentum to achieve kneeling position.
4. Use arms to stabilize the kneeling position to allow the foot to come into a step position.
5. Bring trunk weight backwards with the prosthesis still backwardly extended.
6. Stand up by pushing on arms (holding on to walker or furniture if available) and place prosthesis into stance. Standing can also be

achieved (step 6 repeated) by using the push-pull method. The therapist's hand pull provides momentum to get up.

Make sure the centre of gravity is positioned over the quadriceps. Getting up is difficult to learn and requires repeated practice. Once perfected, the amputee is less afraid of falling because he knows he can get up again.

Wheelchair independence

A programme aiming towards wheelchair independence is considered:
1. When the remaining leg is unreliable.
2. When other medical conditions do not allow the amputee to ambulate with walking aids.
3. When bilateral amputation deprives the elderly of having at least one knee joint.
4. When the amputee has lost all motivation regarding participation in a rehabilitation programme.

Discussion

Although the TK amputation stump has specific advantages over non-weight bearing stumps, the following considerations should not be over-looked:
1. The cosmetic appearance bothers patients more so when sitting because the thigh protrudes and the shorter shin sometimes does not allow for foot-ground contact. This emphasizes the fact that the limb is artificial.
2. The TK amputee practices an unnatural gait pattern (Oberg and Lanshammar, 1982). In normal locomotion, the knee on weight-bearing is held in slight initial flexion. However, the amputee has to stand on a completely extended prosthetic knee, which means he has to hold hip extension somewhat longer on the prosthetic leg compared to the sound side.

Rehabilitation potential of the TK amputee, as with other levels, depends on the general health and on the pattern of ambulation prior to amputation.

Conclusion

Physiotherapy treatments are a vital part of the rehabilitation of the TK amputee. A specific treatment plan is based on the sound knowledge and understanding of normal human locomotion, the health status of the patient, and the biomechanical changes and expected stump

functions resulting from the TK amputation. The TK stump is generally problem free, functional and end bearing, allowing a high rehabilitation rate in independent ambulation and is therefore, well suited for the geriatric amputee.

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The early rehabilitation of lower limb amputees using a pneumatic walking aid

R. G. REDHEAD

The Limb Fitting Centre, Roehampton, London

Abstract

A pneumatic walking training aid for amputees is described. It was developed by the late Biomechanical Research and Development Unit, Roehampton, from an original design by Professor Little in Australia. The walking aid has been used successfully on the majority of below-knee and through-knee patients rehabilitated in the Roehampton Walking Training School since 1976. There have been no complications that could be attributed to the use of the pneumatic walking aid.

Introduction

Early mobilization following amputation is now generally accepted as being an important factor in the rehabilitation programme of all amputees.

To mobilize the patient by allowing him to hop using a frame or crutches only allows the stump to hang down taking no active part in the exercise. This relative inactivity of the dependent stump is conducive to increased stump oedema even when supported by a stump bandage. Many of the older patients find balancing on one leg exhausting and almost beyond their capability. It is therefore desirable that the patient has support from some form of prosthesis on the side of the amputation from the time of starting standing exercises.

The support may take the form of a simple pylon structure with a pre-made adjustable socket as advocated by Devas (1971) for above-knee amputees. With this approach it is difficult to achieve a socket fit that supports the distal stump tissues.

The immediate post-operative fitting of a plaster socket as described by Burgess et al

All correspondence to be addressed to Dr. R. G. Redhead, The Limb Fitting Centre, Roehampton Lane, London SW15 5PR, United Kingdom.

(1965) can be most effective when applied by staff who are experienced in its use. However this technique is difficult to learn to use safely and therefore its use has in the main been confined to specialist units.

Little (1971) described an early walking device which he designed around a pneumatic air splint as a form of temporary socket using a metal frame and prosthetic foot. This device was used as a walking training aid until the stump was ready for a definitive socket fitting. In this report a modified pneumatic walking aid is described. The new device is now in regular use at many of the major hospitals in the United Kingdom. Other centres abroad have reported on the successful use of pneumatic walking aids (Dickstein et al 1982).

The Roehampton pneumatic walking aid

The apparatus designed by Little (1971) consisted of a single compartment pneumatic sleeve long enough to extend from the groin to below the amputation stump. It was enclosed by a tubular frame, having at its lower end an extension tube to a solid ankle cushion heel (SACH) foot. Following initial use of one such device, kindly loaned by Professor Little to the Biomechanical Research and Development Unit, Roehampton, the structure was modified to provide greater stability of the stump within the pneumatic sleeve and to give improved end support. The stability was improved by dividing the air space in the sleeve into anterior and posterior compartments which communicated with each other via a small transfer port. Improved end support was achieved by using a small subsidiary air bag placed in the lower part of the main pneumatic sleeve and invaginated on itself to support the end of the stump. Simple webbing slings supported the distal end of the pneumatic sleeve in the frame and allowed adjustments in length to be made. A simplified
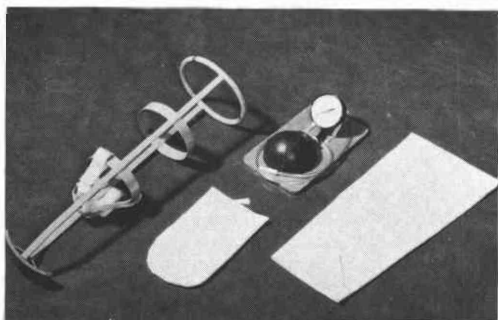
Fig. 1. Roehampton pneumatic walking aid showing support frame, end-support bag, main pneumatic sleeve and foot pump.

support frame was designed with a padded safety ring at the upper end and a simple rocker in place of the SACH foot at the distal end (Fig. 1).

The Roehampton pneumatic walking aid is suitable for patients of widely differing build. It may be used for below-knee and through-knee amputations and with a slightly modified sleeve for above-knee cases.

To apply the walking aid the patient is seated between parallel bars with his stump extended in front of him. The small end-support air bag is positioned over the distal end of the stump and held in position as the long pneumatic sleeve is pulled over this and up to the groin. The frame of the prosthesis is then passed over the pneumatic sleeve and held in place until inflation is complete.

The end-support bag is partially inflated, then the main air bag is inflated to a pressure of 40mmHg using a simple foot pump and pressure gauge. The gauge and pump are removed and the inflating tube is sealed off with a spigot. The patient can then stand so that minor adjustments can be made, and is then able to walk with a stiff knee gait. When the patient bears weight on the socket the air pressure in both bags will rise to 60mmHg or more (Fig. 2).

The apparatus can be worn continuously for a period of 2 hours and can be applied as many times as is necessary in the course of a single day (two periods a day is usual in the course of normal rehabilitation). However, when commencing exercise on the sixth postoperative day or at any time before complete wound healing, the air bag is inflated for periods of 5–10 minutes only during the first day of use and thereafter the time is increased progressively. The appliance is a walking training aid and is intended for use by the patient only under the supervision of trained staff.

Results

The pneumatic walking aid has been used on the majority of patients having below-knee or through-knee amputations who have attended the Roehampton walking school since 1976. Redhead et al (1978) reported on the use of the walking aid in the management of 87 lower limb amputations in 85 patients of mean age 67 years (range 21–94 years). In 6 patients the amputation was of the second leg and 2 patients required bilateral amputations.

Use of the pneumatic aid was commenced from the sixth post-operative day, but owing to delayed wound healing in some patients the mean time to its first use was 17 days (range 6–55 days). A permanent prosthesis was supplied to 80 of the patients as soon as their stumps were healed and showed no volume changes; this was at an average of 40 days post-operatively (range 15–112 days).

Five patients had to be withdrawn from the trial for various reasons not connected with the

Fig. 2. Pneumatic walking aid applied to patient.

use of the walking aid. No complications were recorded from pressure damage to the stump; several patients fell but the pneumatic aid acted as a protection to the stump.

Discussion

Although a long pneumatic splint can be used as a walking aid and is commercially available *(Jobst), stability with such devices has been a problem, (Kerstein 1974), and the addition of the outer frame represented a significant improvement (Little 1972).

Little reported on the use of his pneumatic walking aid in a group of 50 patients, 85 per cent of whom became permanent limb users.

The advantage of a pneumatic walking training aid is that it is an inexpensive piece of equipment that can be kept available for immediate use. While it is being worn it provides protection for the healing stump. The overall contact and the variations of pressure, (40/60 mmHg) during the walking cycle reduces oedema and hastens the shaping and maturation of the stump as venous and lymphatic return is facilitated. General and specific muscle work is being used and, most importantly, the early resumption of a standing posture and the commencement of walking prevent deterioration of postural reflexes, which can happen in spite of intensive physiotherapy if the patient remains bedfast or chairbound. Devas (1971), in a study of 162 patients having surgical amputations, mainly for vascular disease, identified the need for an early walking aid which could be used within a week or two of surgery. While he was able to provide this by using a home-made socket and secondhand parts from discarded prosthetic limbs, it is clearly preferable to have a simple device available in all hospital physiotherapy departments which can be used over and over again for many patients during their rehabilitation. The pneumatic walking aid has obvious advantages over the plaster sockets used in the immediate postoperative fitting techniques when attempting to introduce the concept of early mobilization of the amputee across a wide range of hospitals.

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*Jobst, Box 653, Toledo, Ohio 43694, USA or Jobst Ireland Ltd, Thurles, Co. Tipperary, Ireland.

Minimal staff training is required which makes the use of the pneumatic walking aid attractive to rehabilitation departments. The device has met with the approval of many surgeons because the stump and the possible development of complications are not hidden from view as is the case when a plaster socket has been applied. Experience has shown that the walking aid is safe to use during the early postoperative phase of the rehabilitation of the new amputee. The reaction of the patients to this apparatus is favourable and there is little doubt that a number of patients have been able walk independently through its use who would otherwise have had to accept a wheelchair existence. Most find the gentle pressure comfortable and discomfort in the stump is often eased. Objectively, it appears that oedema is reduced, wound healing is not impaired and volume change in the stump limited, permitting a definitive socket to be made at an early stage.

The Roehampton Pneumatic Walking Aid is now commercially available from:

Vessa Ltd
Paper Mill Lane
Alton
Hants GU34 2PY

Price: £45 each ex. works.

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Tolerance of early walking with total contact among below-knee amputees—a randomized test

E. LIEDBERG, H. HOMMERBERG and B. M. PERSSON

Department of Orthopaedic Surgery, Lund University Hospital, Sweden.

Abstract

In order to reduce the need for repeated changes of socket due to postoperative atrophy and resorption of oedema simple temporary limbs are required to delay the casting of individual sockets until the stump is more mature. A randomized study of 95 below-knee amputees was performed with a re-usable temporary one-size prosthesis of endoskeletal type with adjustable tube length. Total contact was obtained by moulding a thin plastic pillow containing small plastic pellets around the stump in parallel connected sections. As air was evacuated the pillow became rigid. The pillow was kept in place about the stump by Velcro bands. Physiotherapists were able to make all adjustments and ambulate the patient 1–2 hours a day. The training started 2–4 weeks after amputation and lasted for 1–4 weeks. Healing problems due to training did not occur in well healed stumps where training started 3 weeks or more after amputation. No negative influence on maturing of stump, hospital stay and walking ability three months after amputation was found.

Introduction

Immediate postsurgical limb fitting for amputees was introduced by Berlemont (1961). Weiss (1966) and others in the middle of the sixties but it was soon found that elderly people with ischaemic limbs tolerated this much less than traumatic cases (Cohen et al, 1974) and that a postoperative plaster shell gave better healing than immediate prosthetic walking (Mooney et al, 1971). Early fitting replaced immediate fitting

All correspondence to be addressed to Dr. E. Liedberg, Department of Orthopaedic Surgery, Lund University Hospital, S-221 Lund, Sweden.

in most centres. Among predominantly elderly vascular amputees, early fitting has had a tendency to be postponed for 1–2 months to allow safe healing of the wounds and simultaneous reduction of the need for repeated changes of socket due to postoperative muscular atrophy and resorption of oedema.

Therefore, simple temporary limbs for first walking training are wanted. The casting for an individual socket can thus be postponed some weeks until the stump is more mature. Different types of limbs have been designed to meet this need. Some have been made with high ischial support to unload the stump during healing (Devas, 1977; Hierton, 1980). Some have utilized airbags (Little, 1971; Kerstein, 1974; Redhead et al, 1978). Others have used an individually cast temporary prosthesis of differing materials (Ruder et al, 1977); Winkler and Fitzlaff, 1980). The ready-made temporary prostheis tested in this study has a total contact socket, which is moulded on the stump (Henriksen et al, 1978), but in spite of this it is a one-size and ready-made type of aid which does not need any participation from the orthopaedic technical department.

This study was made to examine how it was tolerated by patients and how it influenced healing and rehabilitation.

Material and method

The temporary prosthesis with total contact socket used in this study was an endoskeletal type where the tube length was adjustable by 12 cm.* The foot could be rotated inwards and outwards but not translated antero-posteriorly

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*(Tulpanprotes, LIC, Solna, Sweden).

or medio-laterally. The foot had a single axis moving ankle and was of one-size to fit both left and right side. The socket reached 10–20 cm above the knee joint line and was made up of four separate sides like the petals of a tulip. The width in all directions could be adjusted. A patellar tendon support was placed on the anterior petal to relieve pressure from the patella (Fig. 1). Total contact was created by using a thin plastic pillow with small plastic pellets and several parallel connected sections. This pillow was wrapped around the stump and the air evacuated making it rigid (Figs. 2 and 3). The stump with the pillow was then introduced into the Tulip socket and kept in place by Velcro bands. During this application some adjustments for creating a correct alignment were possible.

Fig. 2. The vacuum pillow about to be wrapped around the stump, fixed with Velcro bands and made rigid by evacuation of air.

The Tulip limb can also be applied to through-knee (TK) as well as below-knee (BK) stumps. About 15 degrees of movement in the knee of a BK amputee was possible within the upper part of the socket. Normally the patients used this limb for 30–60 minutes in the morning and in the afternoon. Application, instruction, training and observation of the effects were performed by the physiotherapists.

This randomized series included 169 patients amputated for ischaemic disease at below-knee level from 1978 through the first half of 1980. All amputations except one were performed with the sagittal skin incision described by Persson (1974). Of the 169 patients, 79 were allocated the use of the Tulip limb, being chosen randomly by picking all patients whose age was an even number. An ischial weight bearing temporary prosthesis was used only if secondary healing of long duration occurred. All patients were treated similarly with physical exercises
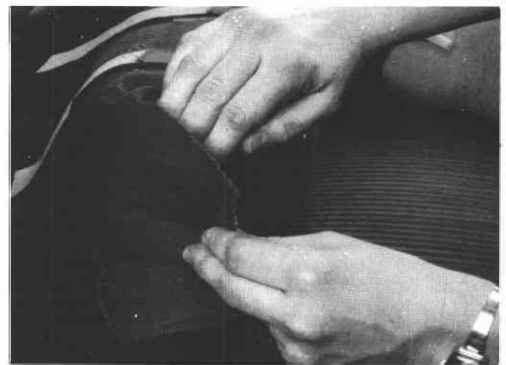

Fig. 1. The ready-made temporary prothesis (Tulip limb), with adjustable length, universal foot, Velcro bands to control width and patellar tendon support.

Fig. 3. Total contact at the end of the stump is achieved by folding the flaps before evacuation of air.

Table 1. Exclusion of patients from study.

Cause	Tulip	Non-Tulip
Dead within 3 months	16	17
Re-amputated within 3 months	8	9
Inaccessible	8	9
Not following randomization	0	7

Table 2. Distribution of patients in test

Sex and side	Tulip	Non-Tulip
Male/female	30/17	21/27
Left/right	28/19	25/23
Uni-/bilat-	38/ 9	38/10
Total	47	48

Table 3. Somatic and mental conditions for prosthetic rehabilitation.

Condition	Tulip	Non-Tulip
Good somatic	25	21
Questionable somatic	16	15
Bad somatic	6	11
Good mental	37	35
Questionable mental	9	7
Bad mental	1	6

Table 4. Primary randomization and final use of Tulip limb.

Use of limb	Tulip	Non-Tulip
Used Tulip limb	35	0
Used other limb	3	9
Used no temp. limb	9	39
Total	47	48

postoperatively. As soon as possible they were jumping in a walking-frame, with the aid of quadrapeds or elbow crutches. The only difference between the groups in relation to rehabilitation was the use of the Tulip limb.

From the 169 patients 74 were excluded for the reasons shown in Table 1. During the last months of the study seven patients in the non-Tulip group erroneously walked with the Tulip limb. These seven patients showed no differences compared to the rest of the non-Tulip group but were excluded. A number of patients were lost from re-examination because they lived at homes or nursing homes far away from the hospital (Table 1). No difference between the groups was found according to distribution of sex, side and number of bilateral cases (Table 2).

Among ischaemic amputees there is a great proportion of elderly patients with other symptoms of cardiovascular disease. A screening of somatic and mental conditions on clinical grounds was therefore done during the first week after amputation and before the plaster of Paris was removed. In one patient the somatic condition was not available. In this way a classification of the rehabilitation potential in the two groups was done (Table 3). The use of Tulip limb is shown in Table 4.

Stump healing was classified as primary or with a minor necrosis (less than 0·5 cm) or a larger necrosis (above 0·5 cm) leading to a secondary healing process. Secondary breakdown of a wound was also noted when occurring.

Using proximal and distal circumferential tape measurements and the length from knee joint to end of stump an arbitrary volume was calculated as a cut cone at 2, 4, 6 and 12 weeks. (Persson and Liedberg, 1983).

Results

Use of the Tulip prosthesis began on average three weeks after surgery (Fig. 4) and the duration of training averaged 2–3 weeks (Fig. 5).

Secondary ulceration on the healed stump occurred in both groups (Table 5). Only one had used the Tulip limb before the secondary ulceration occurred, and the patient began his training only 15 days after the amputation.

Seven patients started Tulip training despite not being healed. In one case the wound diastases increased before the secondary ulceration was healed and in four cases the secondary ulceration healed with careful continuous training with the prosthesis.

Two re-amputations were needed after the use of the Tulip limb. One was a 77 year old diabetic woman wih an infected gangrene midway up the calf. She started her training 19 days after a sagittal amputation despite a minor necrosis ventrally. Training continued for 23 days but after a secondary suture re-amputation was needed. The other was a 49 year old woman with arteriosclerosis obliterans amputated by the Burgess technique after an aortofemoral graft, a femoro-popliteal bypass and repeated tombectomies. There was a necrosis ventrally in the suture line but the patient started her training
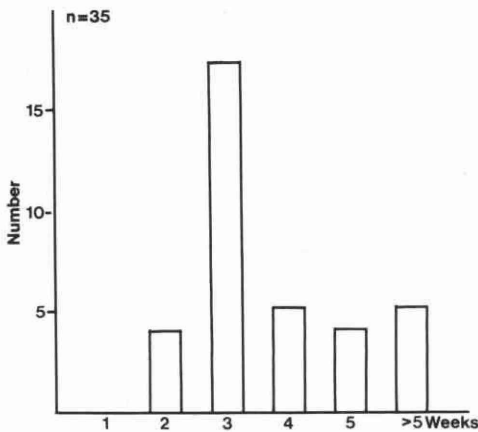
Fig. 4. Time in weeks from amputation to start of training with Tulip limb.

Fig. 5. Duration in weeks of training with Tulip limb.

20 days after amputation for 8 days but the enlarging necrosis led to re-amputation a month later.

The maturity of the stumps was observed by clinical judgement of resorption of oedema and muscular atrophy. The number of days between amputation and plaster casting for making a definitive socket was recorded (Table 6). About three or four patients in both groups were cast for making a socket for definitive limb 1–6 months after amputation and without statistical difference between the groups. Normally the definitive prosthesis was made two months after amputation.

Walking ability three months after amputation was studied by the number of supports (Table 7). Only 10 patients had no or one support and there was no difference between the groups.

To what extent the maturing of stumps was stimulated or disturbed by the use of the Tulip limb was studied by measuring the shrinking rate by proximal and distal circumference of stump and length between joint line and end. Using these measurements a cut cone was calculated as an arbitary volume of stump. There was a decrease in volume of about 7% from first measurement at two weeks to third measurement at twelve weeks, but there was no difference between the groups.

The mean stay in hospital after amputation was 46 days in both the Tulip and non-Tulip groups with median values of 39 and 36 days respectively, and standard deviation of 28 and 41 days.

Discussion

The technique of moulding a vacuum pillow socket directly on the stump as in this study is

Table 5. Wound healing and secondary ulceration.

Healing	Tulip	Non-Tulip
Primary healed (6 w)	25	21
Secondarily healed	10	12
Healed with secondary ulceration	12	15
Total	47	48

Table 6. Time in days from amputation to casting for making socket for definitive prosthesis.

Number and time	Tulip	Non-Tulip
Number of patients	47	48
Number cast	36	35
Mean time	64	63
Median time	45	54
Range	31–181	25–206
SD	41	35

Table 7. Walking status 12 weeks after amputation. Number of patients using canes, tripods and wheelchair.

Walking aid	Tulip	Non-Tulip
No support	2	1
One support	4	3
Two supports	23	22
Wheelchair	18	22
Total	47	48

unique. It is less bulky than the air-bags (Little, 1971; Kerstein, 1974; Redhead et al, 1978) and easier to adjust to the patient than those with ischial support (Devas, 1977; Hierton, 1980).

This clinical test has been going on since 1977 to evaluate the effects on rehabilitation of this temporary limb. Normally it is said that a stump that has healed will remain healed but in this series 27 patients of 95 were found to get secondary breakdown of the wound after being healed (Table 5). Of these 27 only one had started to use the Tulip limb prior to the secondary breakdown and this patient started to use it 15 days after amputation. The secondary breakdown did not occur until the fifth week after amputation and the small breakdown healed despite continuous use of the Tulip limb. Two of the re-amputated patients had used the Tulip limb despite not being healed, starting 19 and 20 days after amputation and they developed accelerating stump problems necessitating re-amputation.

We have observed a small number of patients with reddening and stretching of the suture line when starting training in the second and third week, as also with the two re-amputated cases, and because of this the training was postponed till 21 days after amputation and after the stitches had been removed. Healing problems due to training did not occur in well healed stumps where training started 3 weeks or more after amputation.

The number of walking supports at three months after amputation was the same in the Tulip as in the control group.

The Tulip limb was considered to be an advantage in cases with debatable walking possibilities due to their debilitated general condition. In such cases the physiotherapist could use the Tulip limb for testing walking ability and training the patient for a few days before a decision was made whether to prescribe a permanent limb or not. A more thorough analysis of the problem was unfortunately not included in this study. Especially now, when many patients are over 80 (Liedberg and Persson, 1983), about a third will never be active walkers. Almost half of all the patients in this study had a wheelchair for help at three months.

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Biomechanics of the through-knee prosthesis

J. HUGHES

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

Abstract
The biomechanics of the through-knee prosthesis is considered in detail and comparisons made with the above-knee case. Socket shape and suspension are discussed and comment offered on knee function in both stance and swing phases.

Introduction

The through-knee (TK) is the most distal amputation in which normal knee function is completely lost by the patient on the amputated side. In biomechanical terms the problems are very similar to those of the above-knee (AK) level. There are, however, physical differences which may be of considerable importance in the prosthetic procedure. The end of the stump is composed of tissue normally adapted to weight-bearing in the kneeling position. A long lever arm is available for the exertion of control forces by the hip muscles and the muscles themselves are, for the most part, intact and operating in a physiological condition.

The biomechanics of the AK prosthesis is well documented and understood (Radcliffe, 1970 and 1977), while relatively little attention has been paid to the biomechanics of the TK. It is, therefore, useful to view the problems in terms of the differences which may exist between this level and the AK case.

Socket

The design of any prosthetic lower limb socket must take into account those forces which will be applied between prosthesis and stump during walking. It must provide for the application of

All correspondence to be addressed to Prof. J. Hughes, Director, National Centre for Training and Education in Prosthetics and Orthotics, University of Strathclyde, The Curran Building, 131 St. James' Road, Glasgow G4 0LS, Scotland.

these forces in such a way that load is transmitted to pressure tolerant areas while avoiding pressure sensitive. It must also be fashioned to apply these forces to tissues of varying stiffness, avoiding excessive pressure on the stiffer tissues and minimizing unwanted relative motion due to the excessive compression of soft tissue (Hughes 1983).

A good TK stump can take the largest part of the vertical support load on the end-bearing surface instead of, as in the case of the AK stump, requiring transmission of load to the pelvis by way of the ischium and gluteal muscles. In the medio-lateral plane, the body weight does, of course, exert a toppling effect about the point of support, during the stance phase (Fig. 1). This toppling effect is approximately equal to that which would be experienced were the
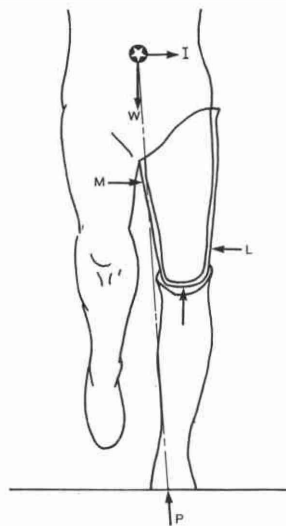

Fig. 1. TK socket—forces in the frontal plane during stance phase.

support ischial and gluteal, as the support point is in almost the same vertical line. The summated effects of the lateral and medial stabilizing forces will, therefore, be required to act in the same general area, i.e. the lateral will be distal and the medial proximal. Because of the greater length of stump, compared to the AK, the area available to apply the forces is increased, implying lower contact pressures between socket and stump. Further, the greater stump length increases the couple arm attainable between the summated force effects therefore reducing their magnitude and further reducing the pressure.

The application of these forces is an important factor, in the design of the socket. If the lateral wall of the socket is not fitted properly to transmit force L (visualize the situation where there is a space between the stump and the socket wall) then the force will be transmitted as a shear force in the tissue of the end of the stump. This is because the end of the stump will still be forced into contact with the socket by the support force.

Figure 2 demonstrates the importance of designing the socket to transmit the medial proximal stabilizing force, M. Figure 2 (left) shows the situation in an AK socket where the support point is in the region of the ischial tuberosity. There will be a tendency for the socket to rotate about this support point. This in turn will tend to move the socket relative to the femur at its distal end. Therefore the femur must be properly stabilized in the socket. However, in the case of the knee-disarticulation prosthesis (Fig. 2 right) since there is usually no ischial support, the rotation will tend to take place about the support point at the end of the stump.

Ineffective stabilization will lead to relative movement between the socket and the top of the femur producing a fleshy "roll". Therefore, the force M must be applied in such a way as to avoid creating painful pressure and there should be a generous flare at the medial proximal brim to minimize the "roll".

Figure 3 shows the force pattern early in stance phase in the plane of progression. To maintain stability the resultant force, R, between ground and foot must pass in front of the knee joint otherwise the external force will tend to flex the knee. The amputee may influence the line of action of this force by extending his hip and "digging" his heel into the floor. This will have the result of reducing RH, the horizontal component of R and thus changing the slope of R so that its action line is more anterior. Consequently the socket must be designed to allow the transmission of this extension moment (that is to transmit force on the anterior proximal and posterior distal aspects).

In the swing phase, (Fig. 4), the forces tending to pull the socket off the stump—due to gravity and inertia—may be balanced by fitting the sockets over the flare of the condyles. In most sockets manufactured from a "window" is provided to allow the bulbous end to pass the narrow area above the condyles. This "window"
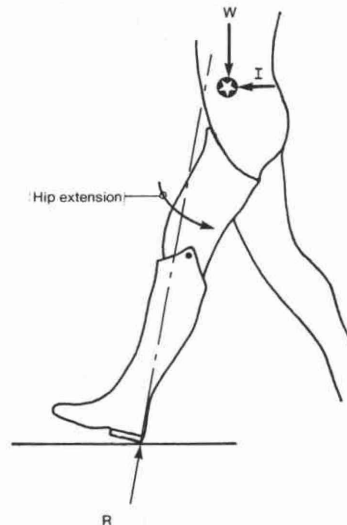

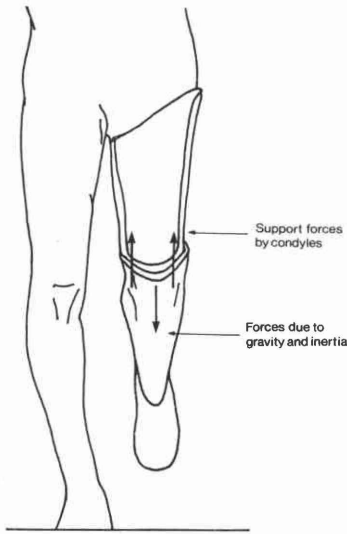Fig. 3. TK socket—forces in the sagittal plane during stance phase.

Fig. 2. Comparison of AK (left) and TK (right) sockets illustrating rotational effects about the point of support.

Fig. 4. TK socket—forces in the frontal plane during
swing phase.

Fig. 5. TK socket—forces on the medial plate during
swing phase.

will be placed on the medial side to avoid the
area which must transmit the lateral stabilizing
force, L. It will be seen from Figure 5 that the
support force by the condyles during the swing
phase will tend to displace the plate used to close
the "window". A strap must be fitted to provide
a horizontal force pulling the plate into the
window and allowing the solid part of the socket
to exert a balancing downward force on the
plate.

Knee function

The functional loss suffered due to the
absence of the normal knee joint is considerable
for the TK amputee as it is for the AK. The knee
joint is capable of a large range of motion,
actuated by powerful muscle groups, and is of
great functional importance in normal
locomotion (Hughes, 1970). Restoration of
locomotion may only be achieved by an
adaptation in gait, optimum utilization of
remaining musculature and the provision of
passive mechanisms. The biomechanical
problem may be considered in terms of (a), the
stance phase and (b), the swing phase. Although
the problems are the same as for the AK
amputee (Radcliffe, 1977), it is useful to
summarize them briefly to set the scene for the
prosthetic procedures at this level.

Stance phase

The requirement is for stability at heel strike
and as the body weight progresses over the

support point, coupled with an ability to initiate
flexion, preparatory to swing through. It is
possible to provide these actions in some
measure, and under voluntary control, by hip
action—extensor muscle action at the hip can
maintain knee extension and knee flexion may
be initiated by hip flexor muscle action. There
are basically three ways in which stability may be
provided mechanically for the amputee who has
a prosthesis with a "free" (articulated) knee.
Firstly, the knee may be aligned in such a
position that it lies behind the load line from hip
to foot—causing the resultant force to pass in
front of the knee joint and therefore render it
inherently stable. Secondly, a so-called
stabilizing device may be provided which
develops, as a result of axial load applied to the
prosthesis, a moment at the knee opposing
motion. Thirdly, a polycentric knee device may
be supplied. This raises the instantaneous centre
of rotation of the thigh and shank in the
extended position. The effect is to reduce the
moment required of the hip to maintain stability
in a potentially unstable situation. Of these
three, only the last does not, theoretically, make
it more difficult to initiate flexion in the later part
of the stance phase.

Swing phase

There are two problems facing the TK
amputee in the swing phase. These are
replacement of quadriceps function in
decelerating the upward movement of the shank
after toe-off (avoiding excessive heel rise) and
replacement of hamstring function in
decelerating the shank in the later part of the

swing phase (avoiding "slamming" into full extension).

These functions cannot be effectively provided under the voluntary control of the hip muscles but can be passively reproduced by mechanisms which develop a moment at the knee, resisting motion. Such a mechanism may operate by the development of mechanical friction in which case it will be suitable for only one rate of cadence since the friction effect will correspond to only one inertia condition. Alternatively the resisting moment may be produced pneumatically or hydraulically in which case an automatic adjustment to different rates of operation is inherent, and of a particularly suitable characteristic in the latter. Additionally there may be an elastic member biased to maintain knee extension. This aids in resisting excessive heel rise and initiating swing through but increases the rate of extension and so aggravates the problem at the end of the swing phase.

Examination of the functional requirements of the stance and swing phases shows that certain functions may be controlled or provided by the hip musculature, whereas others require the provision of mechanical devices—for the meantime available designs are all passive in nature. Furthermore, the problems are exactly the same as in the case of the AK amputee. In terms of those functions requiring the use of the hip muscle groups, the TK amputee is presumably at an advantage over the AK because of the physiological integrity of the thigh muscles and the length of lever arm available. On the other hand, because of the physical restrictions imposed on the provision of mechanical devices, he is in a less advantageous position. The femoral condyles are intact and may have the patella sutured distally. Thus the anatomical knee "centre" is considerably above the end of the stump. The medio-lateral width over the femoral condyles is anatomically normal. Thus the spatial distribution available for the provision of devices is, at best, restricted.

Summary

In conclusion the TK amputee is very similar biomechanically to the AK. The socket problems are apparently somewhat reduced with good end-bearing and large stabilizing areas. The functional replacement, required due to the loss of the knee joint, presents the same problem as for the AK, with enhanced hip control potential, but limitations in the provision of mechanical devices in terms of the relative physical relationship of stump and prosthesis.

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Socket design and manufacturing technique for through-knee stumps

P. BOTTA and R. BAUMGARTNER

Balgrist Orthopaedic Hospital, University of Zurich

Abstract

This paper describes a socket design and manufacturing technique for through-knee stumps, based on 14 years experience with 290 prostheses. The bulbous shape of the stump and its full end-bearing quality requires a socket which has very little resemblance to above-knee sockets. The requirements of the through-knee socket are listed and the manufacturing technique is described and illustrated in detail. Emphasis is put on the quality of the negative plaster mould. The socket is manufactured according to the double wall technique commonly used in below-knee sockets. It provides a maximum of comfort and cosmesis without extra costs.

Introduction

Since 1970, we have been faced with an increasing number of patients presenting uni- or bilateral through-knee (TK) stumps for various reasons. Previous designs with rigid sockets or with a leather corset were mere modifications of the above-knee (AK) socket. They were unable, or only partially able, to take advantage of the particular and superior qualities of the TK stump (Table 1). Furthermore, their comfort, cosmesis and resistance to wear and tear needed to be improved.

The socket for TK stumps has to meet the following requirements:

1. Total surface contact in both the sitting and in the upright position.

2. Total end-bearing quality; in normal anatomy the femoral condyles transmit full weight to the tibial plateau and vice versa.

3. No ischial seat and therefore free motion of the hip joint.

4. Easy doffing and donning with the patient in sitting position, requiring no extra physical and intellectual effort.

5. No straps, laces or suspenders.

6. No, or minimal, extra width or length compared to the normal anatomy of the thigh and the knee.

7. The socket should be able to be fitted with every type of knee joint designed for TK amputation including the possibility of knee locking or swing phase control.

8. No special adaptation of clothing, no extra wear due to the prosthesis.

9. Easy to clean for effective stump hygiene.

10. Minimum of weight without loss of durability with regard to the patient's activity.

11. Possibility to adapt the socket to changes of the stump shape and volume.

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

All correspondence to be addressed to Prof. R. Baumgartner, Balgrist Orthopaedic Hospital, Forchstr. 340, CH-8008, Zurich, Switzerland.

12. Standardized manufacturing technique requiring no extra skill from the prosthetist who is familiar with normal anatomy and current manufacturing techniques.
13. No extra costs compared with conventional prostheses.

Manufacturing technique
Plaster mould

The quality of the socket depends primarily on the quality of the negative plaster mould. Particular attention must be given to the anatomy of the stump end to enable the femoral condyles to transmit full weight on to the prosthesis as they did on the tibial plateau before amputation took place. Accordingly, a maximum amount of end bearing must be achieved in transcondylar TK stumps with reduced weight-bearing surface.

The casting method that has been practised for many years now is rather simple. The negative mould is taken with the patient lying on his back and holding his stump in a position of about 70 degrees of flexion. This provides more comfort and safety for the patient (and also for the prosthetist).

The skin is first covered with an ordinary elastic stocking tube (Tubigrip) sewn at its end and enlarged for the increasing circumference of the thigh at its proximal half. The negative plaster mould must present an exact replica of the shape of the stump. It is preferred to make the negative mould with elastic plaster bandages even though ordinary plaster bandages might also be used.
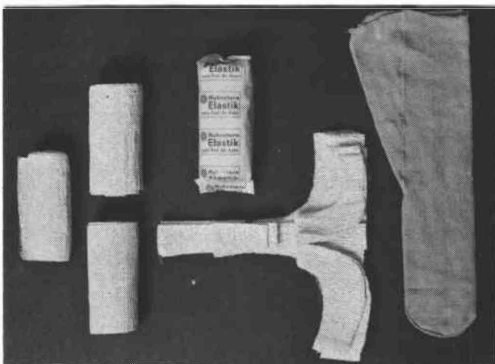
Fig. 1. Material needed for the negative plaster mould. Left, elastic plaster bandages. Centre, pre-cut plaster strips for the intracondylar notch and the dorsal supracondylar area. Right, Tubigrip stocking.

Fig. 2. Lateral view showing modelling of the supracondylar area and the intracondylar notch.

To begin with, several precut strips of plaster bandage are used to cover the end of the stump (Fig. 1). The first strip is applied in a sagittal direction to cover the intracondylar notch. The second strip is applied just behind the proximal border of the condyles and the patella. No external pressure is applied for modelling. As soon as these plaster strips are slightly hardened, more thin layers of plaster bandage are applied to cover the entire stump. Only then is a thin layer of circular plaster bandage added. This cast negative is now moulded with two hands, one gently modelling the intracondylar notch at the dorsal side, while the other provides a snug fit of the plaster cast just proximally to (and not on) the femoral condyles and the proximal end of the patella (Fig. 2). This part is particularly important because it is the only way to provide a really close anatomical fit. It can never be substituted by any sort of stump cushion. The upper end of the socket reaches to 2–3 cm up the groin. This seems to be necessary to control lateral and torque forces.

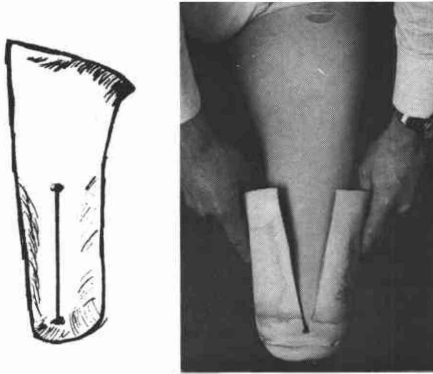The positive cast thus gives a most accurate replica of the stump and does not need further correction.

Fig. 3. Two types of soft sockets. Left, long type.
Right, short type.

Socket

The double wall socket technique transforms
the bulbous stump into a conic one. The inner
liner acts as a cushion between the stump and the
outer socket. It also permits the socket to adapt
to further changes of shape and volume up to a
certain limit.

The inner liner is made from polyethylene
foam. In slim patients, it is preferable to make a
soft socket which is somewhat higher than the
outer socket. To permit easy doffing and
donning, it is longitudinally split in the anterior
part. To avoid tears, two holes of 8–10 mm
diameter are punched at each end of the slit
(Fig. 3, left).

In obese patients and in order to improve
cosmesis, the inner liner is limited to the distal
half of the stump (Fig. 3, right).

The outer socket is rigid only in its distal half;
it becomes gradually softer in its proximal half.
This softness provides a snug fit while sitting and
standing and is particularly appreciated for
comfort and cosmesis. It provides free hip
motion while the long lever of the stump permits
a more natural and less energy consuming
prosthetic gait.

Knee joint

Every prosthetic knee joint designed for knee
disarticulation can be combined with this socket.
The type of prosthetic knee depends on the
patients. In active and younger patients, a knee
with hydraulic swing phase control is preferred.
However, these devices are too heavy for
geriatric patients where a joint with voluntary
locking might be desirable.
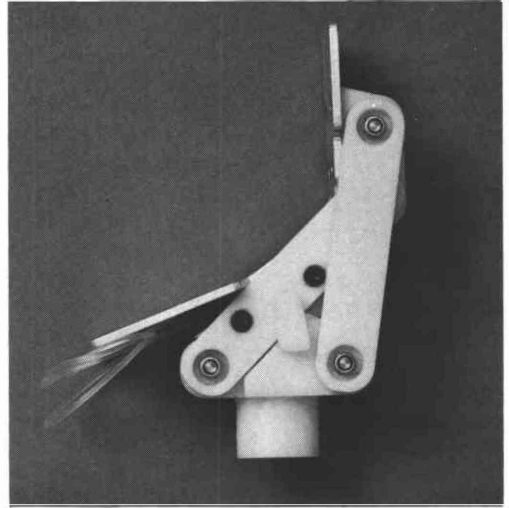
Fig. 4. Ultra lightweight four-bar knee with voluntary
locking mechanism for geriatric patients.

For geriatric patients, an Otto Bock 3K9
geriatric knee was modified by dividing the axis
in two halves thus saving length. Combined with
a SACH-foot, this artificial limb has a total
weight of less than 2,000 g. This solution
however still causes an extra width of 10–15 mm.
which may be partially or even entirely
eliminated later because the soft tissues of the
stump will shrink considerably.

In order to reduce the volume of the prosthetic
knee without adding extra weight, a knee made
from polyethylene (Fig. 4) for geriatric patients
has recently been developed with excellent
preliminary results.

Socket maintenance

Doffing and donning of the socket can be done
by the patient while sitting and without
physical effort. The patient first covers his stump
with a nylon stocking. Some patients prefer to
add a second stocking made from nylon or wool.
The patient then puts on the inner liner which
again is covered with another nylon stocking.
The bulbous stump has now been transformed
into a conic one which enters the prosthesis
easily. The two sockets might be marked with
dots to permit easy identification on the front
side in order to avoid incongruence of the two
liners in the transverse plane.

Cleaning of the inner liner is possible in the washing machine at low temperature; the outer socket is easy to clean with soap and water.

The cosmetic aspect of the TK socket is superior to AK sockets. In mature stumps, there is no more extra width and length which permits the patient also to wear snug pants. To obtain a maximum of cosmesis, the atrophy of the pelvi-trochanteric muscles might be compensated by an extra pad made from Plastazote (Fig. 5).

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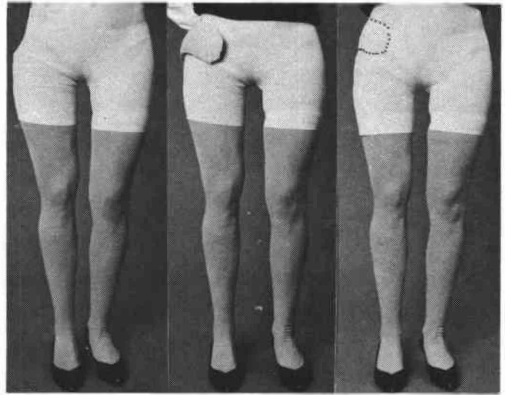
Fig. 5. For better cosmetic results, a pad made from Plastazote compensates the silhouette of the pelvis.

Casting the through-knee stump

E. LYQUIST

*The Society and Home for the Disabled in Denmark, Prosthetic and
Orthotic Department, Copenhagen*

Abstract
The general characteristics of the through-knee
stump are outlined and the casting technique is
described in detail.

Introduction
The most important and difficult procedures
in prosthetic fabrication are associated with the
design and fitting of the socket, which constitutes
the critical interface between the amputee's
stump and the prosthesis.

Regardless of type, the socket must transmit,
in a comfortable manner, the static as well as
dynamic body weight to the remaining part of the
prosthesis, and it must be shaped to provide
stabilization of the stump within the socket so as
to enable the amputee to transfer his own
movements into functional prosthetic move-
ments. If the socket fails to fulfil these
requirements, not even the most sophisticated
knee mechanism and prosthetic foot will
function properly.

The most important steps in the
manufacturing of the socket are the procedures
of taking the negative cast and the consequent
modification of the positive cast.

Through-knee stump characteristics
When the through-knee (TK) amputation has
been performed correctly and no post-operative
complications have occurred, the stump presents
the following characteristics:

1) It is end-bearing, i.e. the body-weight can
be transferred to the prosthesis through the
distal part of the stump.

All correspondence to be addressed to Mr. E. Lyquist,
The Society and Home for the Disabled in Denmark,
Prosthetic and Orthotic Department, Borgervaenget
5, 2100 Copenhagen Ø, Denmark.

2) The long stump provides effective medio-
lateral stability with a minimum of
pressure.
3) The stump musculature has a good
functional status.
4) The distal part of the stump is normally
bulbous; this shape provides an excellent
means of suspension of the prosthesis.
5) Proprioception is good.

With reference to the above mentioned
characteristics, the aim of the casting is to
produce a negative cast where the distal part is
identical in shape to that of the stump, in order to
ensure a comfortable transfer of body weight as
well as providing adequate suspension of the
socket to the stump.

Furthermore, biomechanical analysis indi-
cates that, immediately after heel-contact, the
stump is forced backwards in order to maintain
knee stability. This action continues through the
mid-stance phase of the walking cycle.

Biomechanical analysis also indicates that the
stump is forced laterally during mid-stance,
when the opposite leg is in the swing-phase.

Distal-lateral and distal-posterior pressure
against the stump just proximal to the femoral
condyles must be provided for during the casting
procedure, otherwise problems as a result of
pressure on the distal-lateral-posterior area of
the femoral condyle will result during the stance-
phase, as a consequence of the stump action.

Casting procedure
The casting procedure described assumes that
the amputee is able to stand in an upright
position when casting is performed.

Before casting, circumferential measurements
of the stump—beginning 5 cm (2 in) proximal to
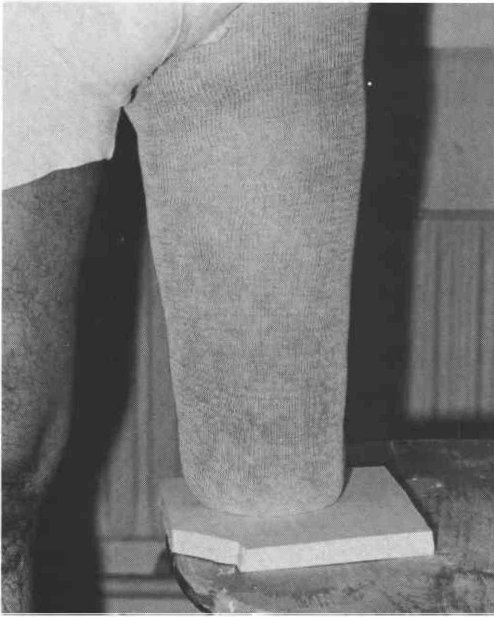the distal surface and continuing proximally with

Fig. 1. The stump, which is supporting about half the body weight, is placed on the adjustable platform.

5 cm intervals to a level approximately 5 cm below the ischial tuberosity—are recorded. These measurements may serve as a guide during the cast modification procedure.

A wet cast sock is applied to the stump and suspended over the shoulder. Have the amputee support approximately half the body weight through the end of the stump, which is placed on an adjustable platform covered with a 2·5 cm (1 in) thick Plastazote (Fig. 1) Adjust the height of the platform until the pelvis is horizontal.

Fig. 2. Following the plaster wrap, pressure is applied on the lateral and posterior aspects of the stump just proximal to the femoral condyles.

Remove the stump from the platform and wrap plaster bandage around the stump, beginning distally and extending proximally to a level approximately 2–3 cm (1 in) below the ischial tuberosity.

Have the amputee resume the position with the stump supported on the Plastazote. Be sure the stump is in normal position with respect to abduction, adduction and flexion-extension.

Apply pressure on the lateral and on the posterior side just proximal to the femoral condyles (Fig. 2).

Before the cast has set, shape the posterior proximal part to be flat (Fig. 3, top), and mould the area corresponding to the Scarpa's triangle (Fig. 3, bottom).

Use of the Plastazote provides exact contours of the distal part of the femoral condyles in the negative cast and secures proper distribution of pressures during weight-bearing.

The flat posterior surface provides sitting comfort, and the moulding of the area corresponding to Scarpa's triangle allows proper
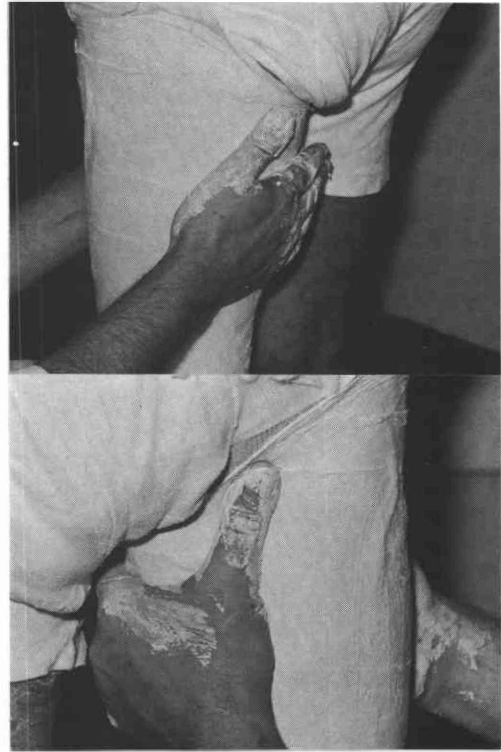
Fig. 3. Top, the posterior proximal area of the cast is flattened. Bottom, the area corresponding to Scarpa's triangle is moulded.

Remove plaster to a depth of about 10mm

Smooth to borderline

Add 3mm plaster in this area
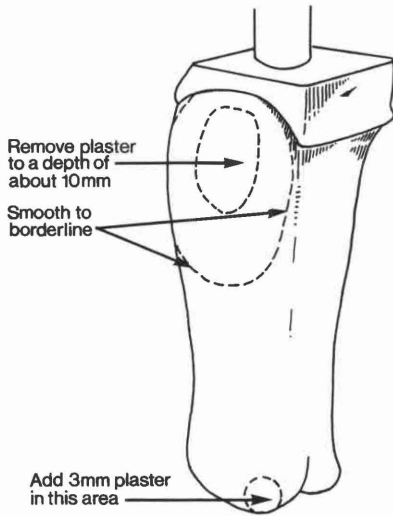
Fig. 4. Modifications to the positive cast.

function of the adductor longus as well as the rectus femoris.

Even the most perfect negative cast cannot constitute a base for a positive mould, which can be used without some modifications. First of all the mould must be smoothed to the depth of the impressions of hands and fingers. Secondly the mould must be smoothed all over.

Additional plaster must be removed on the lateral-proximal area as indicated in Figure 4—the socket having a tendency to be loose in this area.

Add 3 mm (⅛ in) to the distal-lateral-posterior area as indicated in Figure 4 in order to avoid pressure on this critical area.

The socket produced over the mould may include a soft liner or may be a hard socket with a medial window similar to the design of the Canadian Syme Prosthesis. A soft distal pad is used in the hard socket.

Knee mechanisms for through-knee prostheses

K. ÖBERG

Biomechanics Laboratory, College of Health and Care, Jönköping, Sweden.

Abstract

The most widely used knee mechanisms for through-knee amputees can be characterized as three principal types of design. These types are metal side bars with heavy duty joints, conventional knee mechanisms for above-knee amputees and special polycentric linkage mechanisms for through-knee amputees. An investigation in Sweden in 1979 showed that over 50% of the fittings were using the special polycentric linkage mechanisms for through-knee amputees.

The stability diagram illustrates how voluntary and involuntary stability can be utilized by using different polycentric linkage mechanisms for through-knee amputees. The polycentric linkage mechanism can be designed for different stance phase characteristics as well as incorporation of different swing phase control mechanisms. The cosmesis of the available designs is acceptable but there is need for lighter and more compact designs especially for the young and small amputee.

Introduction

Since the technical development of prosthetic components and mechanisms has paid attention to the needs of the through-knee (TK) amputees, the variety of knee mechanisms has increased. Many are designed for above-knee (AK) amputees and adapted to the TK amputee but there are also knee mechanisms that are originally designed for TK amputees. These mechanisms can in turn also be used by the AK amputee.

All correspondence to be addressed to Dr. K. Öberg, Biomechanics Laboratory, Munksjöskolan, Box 1030, S-551 11, Jönköping, Sweden.

Design principles

The most widely used knee mechanisms for TK amputees can be characterized as three principal types of design (Fig. 1). The first type, and in early years the most common prosthesis, incorporates a leather socket with metal *side bars and heavy duty joints* similar to those used in some types of knee orthoses or below-knee prostheses. The prosthesis often has a lumpy and uncosmetic appearance at the knee because of the width and the bulge. With these side joints it is also impossible to incorporate any type of device to control the stance and swing phase characteristics of the knee.

The second type, and still often used prosthesis for TK amputees, employs the large variety of *knee mechanisms for AK amputees*. The major and decisive disadvantage of this type is the lengthening of the thigh and the consequent shortening of the shank. This affects the comfort and cosmesis when sitting as well as the functional characteristics in walking. The advantages are however the availability
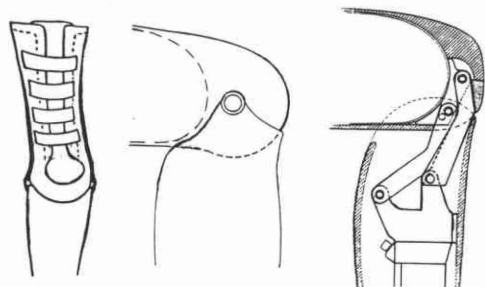
Fig. 1. Three principal types of knee mechanisms for TK amputees. Left, side bars with joints. Centre, conventional mechanism for AK amputees. Right, specially designed polycentric linkage for TK amputees.
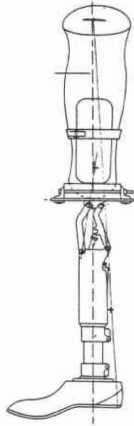
Fig. 2. The OHC polycentric knee disarticulation
prosthesis.

and the variety of functional characteristics.
Mechanisms which allow the mounting of the
stump socket as near the pivot as possible are
preferably used. The lengthening of the thigh
will then be minimized.

The third, and a more recently offered, type of
knee mechanism for TK amputees is the
polycentric linkage mechanism. The most
common type of mechanism is the four-bar
linkage, which has been used in knee
mechanisms for AK amputees. Their advantages
and functional characteristics are analysed and
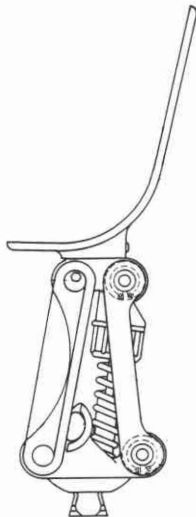
Fig. 3. The Otto Bock modular polycentric knee
disarticulation prosthesis.
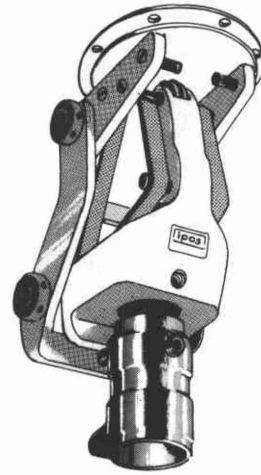
Fig. 4. IPOS-Balgrist polycentric disarticulation knee
joint.

described by Radcliffe (1957 and 1970). The
behaviour of the linkage mechanisms with
regard to the location of the centre of rotation
offers the possibility of placing the mechanism of
a TK prosthesis within the shank but below the
stump in the sitting position. The first design for
this purpose was the OHC Polycentric Knee
Disarticulation Prosthesis developed by Lyquist
at the Orthopaedic Hospital in Copenhagen
(Fig. 2). This knee mechanism is now produced
by United States Manufacturing Company.
Later, other knee mechanisms of this type for
TK amputees were introduced to the market, for
example from Otto Bock (Fig. 3) and IPOS (Fig.
4) in West Germany. These mechanisms provide
acceptable cosmesis and different stance phase
stability characteristics. Different swing phase
controls are also incorporated, such as
pneumatic, hydraulic or friction controls. For
geriatric TK amputees a manual lock is
incorporated in the four-bar mechanism.

Experimental investigations and clinical use of
other types of knee mechanisms for TK
amputees can also be found. At the University of
California, Berkeley, the possible advantages of
using six-bar linkage mechanisms have been
investigated (Fig. 5). This linkage offer the
possibility of increased range of knee motion,
better cosmesis, improved stance phase stability
and swing phase control as compared to four-bar
designs. These advantages are achieved at the
expense of added weight and complexity.
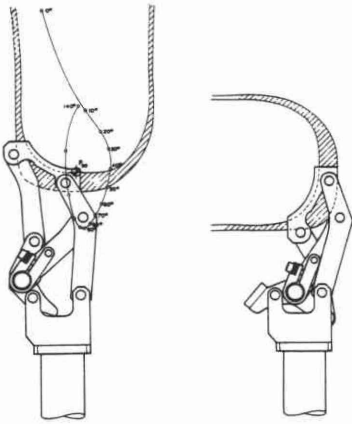
Fig. 5. A compact six-bar linkage from University of California, Berkeley.

Another interesting design made in Holland has been used in both West Germany and Holland. The tube of the shank is connected by rolls to a track in a metal arch that is fixed to the posterior part of the end of the socket. The centre of rotation between the shank and the thigh will then be located within the femoral condyles. For information on clinical experience Dr. Georg Neff, Orthopädesche Klinik und Poliklinik der Universität Tübingen, West Germany is recommended as reference.

TK-mechanisms fitted by Een Holmgren and LIC Orthopaedic companies 1979

In order to investigate what influences the choice of prosthetic knee mechanism when fitting TK, AK and hip disarticulation amputees a survey of the clinical practice was carried out at the orthopaedic clinics in Sweden that are served by the orthopaedic companies Een-Holmgren and LIC. This survey was presented at the ISPO World Congress in Bologna (Haggland and Öberg, 1980) and by Öberg (1980). A total of 471 fittings were investigated of which only 28 (6%) were TK prosthetic fittings. The knee mechanisms used for the TK amputees are presented in Table 1 and divided into three categories with regard to stance phase stability.

Free single axis and unstabilized knees made up 13 (46%) of the fittings and were dominated by the special TK designs such as the OHC knee. There was also one single axis Otto Bock modular knee designed for long stumps. It should be noted that the Otto Bock modular polycentric knee 3R21, which belongs to this category, was not available on the Swedish market at the time.

Weight-bearing controlled single axis and stabilized polycentric knees made up 8 (29%) of the fittings and were of different types but 4 of them were a special TK mechanism known as the

Table. 1. TK mechanisms fitted by Een-Holmgren and LIC orthopaedic companies, 1979.

Stance phase stability	Producer	Item	Number
Free single axis knee	Blohm	Orthotic joint (pair)	1
or	Otto Bock	3R16 Modular knee	1
Understabilized	United States		
polycentric knee	Manufacturing Comp	Disarticulation knee	1
	,,	OHC-knee with pneumatic swing phase control	1
	,,	OHC-knee with hydraulic swing phase control	9
			13
Weight-bearing controlled	Otto Bock	3P23 Jüpa knee	1
single axis knee	,,	3R15 Modular brake knee	2
or	,,	3P31 Lang condylar knee	1
stabilized polycentric knee	IPOS	0955 Balgrist polyc. knee	4
			8
Knee with manual lock	Protesindustri	P450–30 Geriatric knee	1
	Otto Bock	3R17 Modular knee	4
	Custom made	without knee mechanism	2
			7
		Total	28

Balgrist knee made by IPOS from West Germany.

The remaining 7 (25%) fittings were of manually locked knees, including two prostheses without knee mechanisms. None of them were however polycentric linkage mechanisms. Only one prosthesis was fitted with sidebars and orthotic joints. In only 28 prosthetic fittings there were 11 different knee designs from 5 different producers. Fifteen (54%) of the fitted prostheses used specially designed polycentric linkage knees for TK amputees. However, 1979 might be considered an early year for these designs on the market and it could be expected that they are more used in TK prostheses nowadays.

Biomechanics of polycentric knee mechanisms

A polycentric knee joint is polycentric because the instantaneous centre of rotation between the thigh and the shank changes as the knee flexes. This change of knee centre location is designed in a linkage mechanism to move in a manner which combines an improved stability of the knee and a good sitting cosmesis for a TK amputee. The polycentric linkage mechanism also allows an increased range of knee flexion and swing control devices of different types can be added.

The most common type of linkage mechanism for polycentric knees is the four-bar linkage. The location of the instantaneous knee centre can easily be found at the intersection of the two lines that pass through a pair of joints respectively that are connected by a linkage between the shank and thigh (Fig. 6).
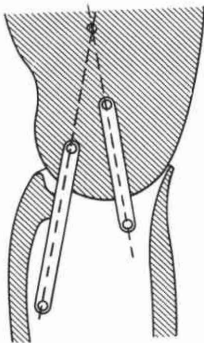
Fig. 6. The four-bar knee linkage and the instantaneous centre of thigh-shank rotation.
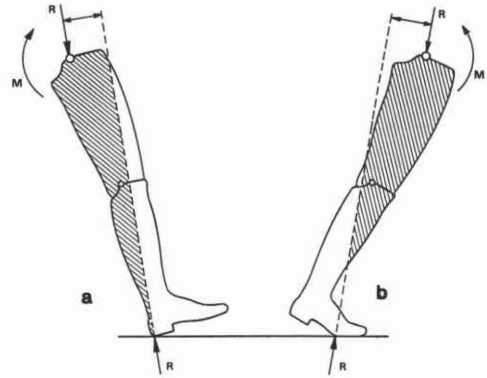
Fig. 7a. The load line at heel contact and hip extension moment. Fig. 7b. The load line at push-off and hip flexion moment.

The stability characteristics of any prosthetic knee can be described by the relationship between four factors:
—the muscular hip moment
—the load line
—the instantaneous centre of thigh-shank rotation
—the brake moment generated by the knee mechanism.

A muscular hip extension moment gives in addition a forward floor reaction force which changes the direction of the loadline ahead of the hip joint as shown in Figure 7a. A muscular hip flexion moment gives a backward floor reaction force which changes the direction of the load line behind the hip joint (Fig. 7b). When the amputee is exerting a hip extension moment at heel contact and the load line has moved in front of the knee joint, knee stability has been achieved (Öberg and Lanshammar, 1982). When the amputee is exerting a hip flexion moment at push-off and the load line has moved behind the knee joint, the prosthetic knee will be flexed while the prosthesis is still supporting the body weight. Voluntary knee flexion under load at push-off is important in achieving an aesthetic and energy saving gait.

When the load lines from heel-contact and push-off are drawn on the leg in the same diagram a stability diagram has been achieved according to Professor C. W. Radcliffe at the University of California, Berkeley, USA (Fig. 8). When combining the two regions for the knee centre when it is stable during heel-contact and can be flexed under load at push-off a common
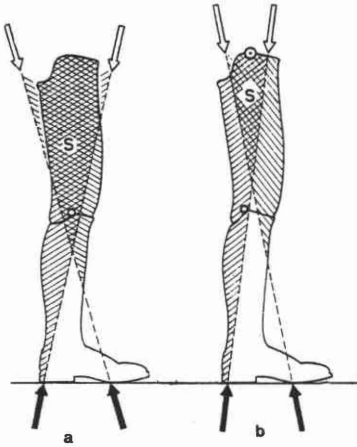
Fig. 8. Stability diagram (after Radcliffe), a) large zone of voluntary stability, S b) less hip muscle contraction and a reduced zone of voluntary stability, S.

region is defined. Radcliffe has called this region, the zone of voluntary stability. In Figure 8a the voluntary hip muscular extension and flexion moments exerted by the amputee are of such magnitude that they give a large zone of voluntary stability. In this case a simple single axis knee is sufficient for maintaining stability at heel contact and ease of flexion during push-off.

Figure 8b shows a more typical situation where the amputee either has reduced hip moment capabilities or prefers to use his hip musculature at less than maximum strength under ordinary conditions. In this case the zone of voluntary stability is dramatically reduced. The prosthetist must under these circumstances, when fitting a single axis prosthetic knee joint, align the knee joint with its centre behind the load line for heel contact in order to ensure knee stability. Such a location is also behind the other load line. The result is a stable knee at heel contact but a knee which is difficult to flex under load at push-off.

These stability diagrams indicate that less hip muscular contraction gives a reduced zone of voluntary stability. A reduced zone of voluntary stability would require a higher location of the instantaneous centre of knee rotation in order to maintain voluntary control of knee stability. Single axis knees provide little or no opportunity to make practical use of this fact because a significant change in the vertical position of the knee joint is cosmetically unacceptable. The polycentric knee however can be designed with

the initial instantaneous centre of rotation located above the usual knee joint and within the zone of voluntary stability (Figure 9). This type of prosthesis requires reduced hip muscular contraction for knee stabilization and can be classified as an under-stabilized knee.

When there is no hip muscular extension ability or the amputee is not willing to depend upon this muscular contraction, the knee mechanism must be stabilized in an automatic way. For AK amputees it is very common to use some sort of weight-bearing controlled friction brake knee. For TK amputees this type would be unacceptable because of the cosmetic consequences. A polycentric linkage mechanism would also here offer an acceptable solution by locating the initial instantaneous centre of rotation behind the hip moment free load line between the heel and the hip joint. A knee design of this sort can be classified as a stabilized polycentric knee.

When involuntary knee flexion or uncertain knee extension happens, as for geriatric amputees, a manual lock incorporated in a polycentric linkage knee mechanism would be a suitable solution.

Discussion

When fitting a TK amputee with a polycentric linkage, the thigh lengthening will be 25–30 mm because of the proximal joints of the mechanism.
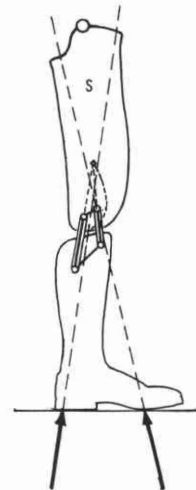

Fig. 9. Understabilized four-bar linkage for voluntary control of knee stability.

This disadvantage is acceptable and the cosmesis that nowadays can be achieved with such mechanisms is usually superior to that achieved with any of the other types of mechanisms.

It has been shown that varying stability and stance phase characteristics can be achieved with the polycentric linkage knee mechanism with regard to functional demands of amputees with different activity level. Also a variety of swing phase mechanisms can be used in these special designs for TK amputees.

Young, small, but active amputees can have difficulties in utilizing the functional features of the TK mechanisms because of the weight of the mechanism and the space in the leg that is required by the mechanism. In general it seems that most of the mechanisms that are available today are heavy. A good exception is the 25 mm system with a four-bar linkage knee from Hanger, England. This design can be used for younger and smaller amputees. For the future, lighter and more compact knee mechanisms are to be wished for the TK amputees.

It is thought that the specially designed knee mechanisms of today for TK amputees have made an important contribution to their rehabilitation. These mechanisms might even be expected to have influenced the increase of TK amputations as an alternative to AK amputations.

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Life expectancy and social consequences of through-knee amputations

J. STEEN JENSEN

Departments of Orthopaedic Surgery T-2 and T-3, Gentofte Hospital, Copenhagen

Abstract

Amputation surgery for gangrene of the lower limb has two primary goals, to save life and to bring the patients back to their previous living conditions. If this can be achieved with restored walking ability the result of the treatment is considered a full success.

The purpose of this paper is to describe the risk of death and possibility of returning through-knee amputees to their own home, relating the results to other major levels of amputation of the lower limb.

Patients and methods

This series includes 310 patients with 320 amputations performed during the years 1971–1979. All amputations were due to gangrene of the lower limb. The mean age of the patients was 70 years (range 40–94)

Based on a retrospective examination of the records the placement before and after discharge from hospital was recorded as well as the mortality rate. Life tables for a comparative number of inhabitants were calculated from the official statistics.

For the calculation of life tables a decrement analysis was used and comparison made by Gehan's modified Wilcoxon test. For supplementary analysis Chi-square test, multivariate logistic analysis and multiple contingency tables were applied.

Results

The primary level of amputation was through-knee (TK) in 21 per cent, above-knee (AK) in 33 per cent and below-knee (BK) in 46 per cent of cases (Table 1). The choice of level was

All correspondence to be addressed to Dr. J. Steen Jensen, Department of Orthopaedic Surgery U, Rigshospitalet, University of Copenhagen, DK-2100, Copenhagen Ø, Denmark.

significantly related to age, as the number of BK amputations decreased and AK amputations increased, whereas the number of TK amputations was constant ($P < 0.03$).

The final level of amputation is influenced by the mortality in hospital and local wound complications leading to re-amputations at higher level. The final levels are listed in Table 1 following re-amputation after TK amputations in 20 per cent (13/66) and after BK amputations in 20 per cent (28/143) of cases. Consequently discharge from hospital could take place in 265 cases.

The primary level of amputation was used for the comparison of mortality statistics because this was influenced by the degree of local ischaemia and the general condition of the patient, which is affected by the systemic toxic effect of the gangrene.

The mortality rate in hospital is of less interest, as it is influenced by the duration of hospital stay, which was on average 77 days after TK, 47 days after AK and 81 days after BK amputations. A more meaningful impression of the systemic effect of the gangrene, as described by the choice of amputation level, is given by comparing the mortality rates 3 months after amputation. As seen from Table 2 the death rate at this time is about 22 per cent and is increasing with selection of a higher level of amputation. The table also demonstrates that the TK amputation is on average midway between the AK and BK levels

Table 1. Primary level of amputation in relation to level at discharge from hospital.

Level	Primary	Final
TK	66	48
AK	111	116
BK	143	101
Total	320 limbs	265 limbs

Table 2. Mortality rate in relation to primary level of amputation.

Level	3 months	1 year	3 years	5 years
TK	21% (14/66)	39% (26/66)	58% (38/66)	67% (44/66)
AK	40% (41/103)	54% (56/103)	70% (72/103)	77% (79/103)
BK	10% (14/141)	17% (24/141)	31% (44/141)	63% (89/141)
Total	22% (69/310)	34% (106/310)	50% (154/310)	68% (212/310)

not only anatomically, but also concerning the risk of death. This feature continues for the first five years postoperatively.

In Figure 1 the life expectancy is demonstrated for the average patient series and the three levels of amputation in relation to the expected survival rate. Although the level of amputation and age were significantly related further statistical analysis demonstrated the primary amputation level to be the most determining for the death rate ($P < 0.0005$), whereas age only had secondary influence ($P < 0.01$) on the long term prognosis of survival. The life-tables also demonstrate that the excess mortality continues for 6 months following AK amputation, 1 year following TK and 5 years following BK amputations.

Table 3 demonstrates the relations between choice of amputation level in accordance to the living conditions. A total of 18 per cent (55/320) of patients were living at institutions for long term nursing care prior to admission. For the purpose of prosthetic fitting the most possible distal level was chosen in patients admitted from home. Consequently only one third of patients had a primary AK amputation performed and every fifth a TK amputation. Among patients admitted from nursing homes the more distal

levels were often chosen to preserve leg length and thus stability in the sitting position.

Table 3. Placement on admission to hospital in relation to primary level of amputation.

Level	Admitted from home	Admitted from nursing home
TK	53 (20%)	13 (24%)
AK	82 (31%)	29 (53%)
BK	130 (49%)	13 (23%)
Total	265 patients	55 patients
Mean age	70 years	78 years

In Table 4 the placement after discharge from hospital is listed. It is seen that patients discharged to institutions for long term nursing care had generally higher levels of amputation than those discharged to their own home.

Table 4. Placement after discharge from hospital in relation to final level of amputation.

Level	Home	Rehabilitation institution	Nursing home	Total
TK	26 (18%)	3	19 (40%)	48
AK	55 (38%)	16	45 (39%)	116
BK	64 (44%)	14	23 (23%)	101
Total	145 (55%)	33 (12%)	87 (33%)	265

Table 5 demonstrates that only every fifth patient was discharged to a nursing home following survived amputation among those previously living in their own homes. The risk of final placement at an institution for long term nursing care is increased with the height of the amputation level.

Table 5. Final placement and amputation level for patients admitted from own home.

Final level	Home	Nursing home
TK	29/37 (78%)	8/37 (22%)
AK	68/91 (75%)	23/91 (25%)
BK	77/91 (85%)	14/91 (15%)
Total	174/219 (79%)	45/219 (21%)
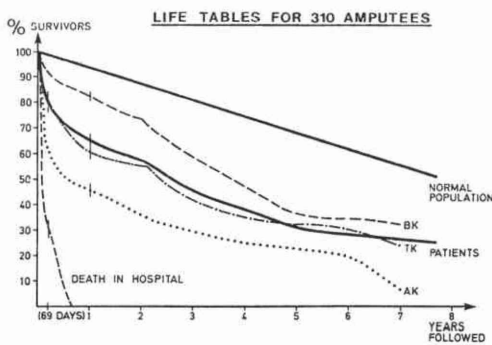
Fig. 1. Life expectancy for BK, TK and AK levels of amputation related to normal expected survival rate.

Discussion

The primary goals of amputation surgery were fulfilled in 66 per cent (174/265) of patients admitted to hospital from their own home for amputation because of gangrene of the lower limb, as they returned alive to their previous surroundings. Among patients admitted from institutions for long term nursing care 76 per cent (42/55) survived and returned to their life in total dependence of other people. It is well known from previous publications that amputations are followed by a high immediate mortality; nearly every third patient dies within one year (Ebskox and Josephsen, 1980, Mandrup-Poulsen and Jensen, 1982). It is clearly demonstrated in this study that the mortality is related to the primary level of amputation in both the short and the long term. This is obvious for the immediate mortality, as the choice of amputation level is determined by the extent of the gangrene and consequently the systematic effect of toxic products released from the gangreneous leg. That the same influence on mortality is noted for years might suggest a more extensive arteriosclerotic disease, which also can explain the stronger relationship to age than to the level of amputation.

There is no doubt that for the majority of these elderly patients with a mean age of 70 years it is most important to be able to return home, although their spouse might have difficulties in accepting the partial lack of a limb. This paper clearly demonstrates that the TK amputation lies midway between the BK and the AK amputation in relation to the chances of survival and of returning to previous surroundings. The prognosis for future walking with a prosthesis is described in another paper in this issue.

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Failures in through-knee amputation

R. BAUMGARTNER

Balgrist Orthopaedic Hospital, University of Zurich

Abstract

Long-term results over a period of more than 10 years give evidence of the superiority of the through-knee compared to the above-knee stump. However, failures in through-knee stumps before, during and after operation and pitfalls in prosthetic fitting are still too frequent. They are mostly due to errors because the peculiarities of the stump and the prosthetic management are not recognised. This paper emphasizes frequent causes of failure in the selection of the level of amputation, the operative technique, post-operative treatment and prosthetic rehabilitation in order to reduce the complication rate.

Introduction

In comparing knee disarticulation versus above-knee amputation in detail, the author tried to encourage surgeons and prosthetists to give priority to through-knee (TK) and not to above-knee (AK) amputation whenever possible (Baumgartner, 1979). The message was understood by many colleagues who, in turn, are recommending the procedure (Vaucher and Blanc, 1982; Stirnemann and Althaus, 1983). Other colleagues gave up this procedure because they had too many complications and failures and therefore again give preference to AK amputation with less wound healing problems regardless of the further results of overall rehabilitation. In fact, complications in TK amputations are still too frequent and are reported to be as high as 25% (Stirnemann and Althaus, 1983). The purpose of this paper is to analyse these pitfalls in order to reduce the complication rate and to improve the possibilities of rehabilitation.

All correspondence to be addressed to Prof. R. Baumgartner, Balgrist Orthopaedic Hospital, Forchstr. 340, CH-8008, Zurich, Switzerland.

1 Level of amputation

It is understood that even a short below-knee (BK) stump is better than any method of TK amputation as long as the BK stump is free from pain, permits a total surface contact with the prosthetic socket and the function of the knee joint is not impaired by trauma or by severe osteoarthritis. As in any level of amputation, the feasibility of a TK amputation mainly depends upon the quality of the tissues which in turn is given by a sufficient blood supply. A loss of sensation or a femoral fracture are no contraindications.

The assessment of a sufficient tissue blood flow therefore represents the main problem. Despite the many laboratory tests to investigate local blood circulation, anamnestic and clinical findings before and particularly during surgery are still of primary importance. As for the main arteries, an obliteration of the popliteal artery might still permit a short BK stump to be obtained. Also, the obliteration of the superficial femoral artery does not represent a contraindication for a TK level as long as it was not due to a sudden occlusion by embolism or trauma. An occlusion of the iliac artery, however, requires an AK amputation at the level of, at least, the middle third of the femur.

The observation of local blood circulation is most important in the assessment of tissue viability. In some cases, primary wound healing may still be obtained without a single artery having to be clamped. Attention must be given not only to the arteries, but also to the veins. Venous thromboses are bad signs and justify a higher level of amputation.

The skin must cover the entire surface of the stump without the slightest tension. The skin flaps must be large enough in order to compensate for the remarkable skin retraction during the operation.

Severe contractures of the hip joint which persist under anaesthesia also suggest an AK rather than a TK level.

2 Operative technique

The patient lies in the supine position with the pelvis slightly elevated by a cushion. The hip and knee joints are allowed free motion to permit easy access to the posterior part of the femur.

In order to obtain primary wound healing especially in vascular patients, the surgeon must minimize tissue damage by using atraumatic techniques and by reducing to a minimum the amount of suture material in the wound. In vascular patients, the tourniquet should not be used. With this philosophy in mind, every deep suture and ligature are avoided and arterial grafts are also removed by making first an incision at the inguinal ligament to disconnect the graft and to pull it downwards. The edges of the femur must be carefully rounded with a rongeur or the file. In transcondylar amputations, the patella has to be removed through the same incision.

Wound drainage is of utmost importance. There is no space for a haematoma which will damage the soft tissues and may lead to necrosis and infection. Whatever type of drainage is used, it has to be safe for 48–72 hours.

3 Postoperative management

In the postoperative management of the stump, again every effort must be made to obtain primary wound healing. Whether a soft, semi-rigid or rigid dressing is applied, its purpose is to reduce the postoperative oedema, to protect the stump from infection and to prevent pressure sores.
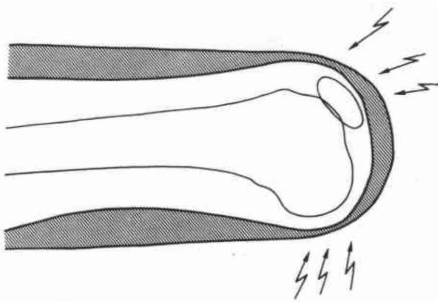
Fig. 1. Pressure sensitive areas of the through-knee stump.

The peculiar anatomy of the TK stump needs special precautions in wound dressing. The dorsal sides of the condyles and the patella are extremely sensitive to external pressure (Fig. 1). In the neutral position, the stump always goes into slight external rotation. This means that even with a patient lying in bed, the lateral condyle is at the lowest level and therefore particularly in danger. It must be relieved by a thick pad applied dorsally in the supracondylar area. The situation is very much the same as in the heel and the Achilles tendon. The dorsal part of the condyles is particularly sensitive to pressure sores if the operative scar is placed transversely and not sagitally (Fig. 2). If there is still evidence of skin necrosis, stitches should be removed immediately. If underlying bone becomes visible through the wound, surgical stump revision should not be postponed.

Fig. 2. Breakdown of an incision placed in transverse direction.

4 Prosthetic management and rehabilitation

Every TK stump is very sensitive to external pressure in the first weeks. Stump bandaging directly on the skin is unable to provide uniform external pressure and might cause pressure sores (Fig. 1). The patella and the condyles need careful padding before any type of dressing is applied. Total end-bearing can only be obtained gradually within the first 4–6 weeks after surgery. To avoid pressure sores, the best results are obtained by starting gait training with the inflatable plastic bag prosthesis. It permits partial weight-bearing and applies homogenous

external pressure and accelerates stump shrinking. Only 3–6 weeks after surgery, the final prosthesis is prescribed (Botta and Baumgartner, 1983). In order to permit easy adaptation of the socket and of the alignment, this prosthesis is not completed for 1–2 months. After 6–12 months, the socket often has to be replaced completely.

As with every amputation stump, the TK stump undergoes significant shrinkage within the first weeks and months. Since the limits between too little and too much pressure are very small in the condylar area, the prosthesis requires frequent adaptations of the soft socket. Even in the area of the condyles the stump will finally shrink in diameter by 10–15 mm within the first 6–12 months. (Fig. 3). This will permit a prosthetic fitting with little or no extra width and length, but requires a particularly well adapted socket in all the three dimensions. At any time,
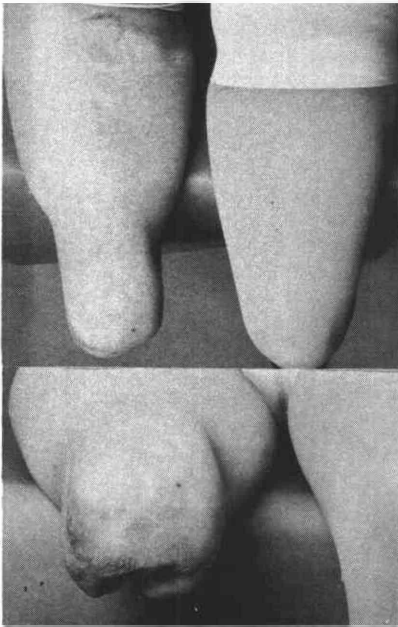
Fig. 3. Shrinking of the mature stump permits prosthetic fitting with little or no extra width and length.

the entire distal surface of the femur must be involved in end-bearing. On the other hand, the patella needs to be completely relieved of external pressure. The patients appreciate being able to move the patella a few millimetres up and down while wearing their prosthesis.

The thigh part of the socket must not be circular, but oval according to the anatomical shape of the thigh even if the outer socket is made from flexible material. If it is too hard, discomfort and pressure sores might occur at the prosthetic rim.

With this enumeration of frequent errors in TK amputation and prosthetics, it is hoped that the number of complications will be reduced. As in every amputation level, however, it will not be possible to eliminate them completely.

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Success rate of prosthetic fitting after major amputations of the lower limb

J. STEEN JENSEN and T. MANDRUP-POULSEN

Departments of Orthopaedic Surgery T–2 and T–3, Gentofte Hospital, Copenhagen

Abstract
Rehabilitation after amputation at through-knee level is described and analysed in relation to amputations at above-knee and below-knee levels.

Introduction
In dealing with amputation surgery for gangrene of the lower limb the most important result for the patient and the family is to get the amputee back home. For the orthopaedic surgeon and the prosthetist the professional demands also include considerations of regaining some walking ability. In modern industrialized countries we often find a wheelchair bound amputee as a result of a failure of surgery.

The purpose of this paper is to describe the number of patients being successfully fitted in relation to the three major levels of lower limb amputations.

Patients and methods
The total series included 320 lower limb amputations in patients with a mean age of 70 years (range 40–94) following gangrene due to diabetic or arteriosclerotic complications.

At discharge from hospital 265 limbs were available for prosthetic fitting. A total of 178 patients were discharged to their own homes, possibly after a period in a rehabilitation institution, whereas a further 87 patients were discharged to an institution for long-term nursing care, including 45 patients originally living in their own home.

All correspondence to be addressed to Dr. J. Steen Jensen, Department of Orthopaedic Surgery U, Rigshospitalet, University of Copenhagen, DK–2100 Copenhagen Ø, Denmark.

In all patients with a walking capacity prior to amputation prosthetic fitting was attempted. When walking was achieved between parallel bars with a preliminary prosthesis the patients were discharged for further ambulatory training. The results analysed in this paper are those obtained at discharge from the out patient clinic or in acknowledgement of definite failure of attempted fitting at discharge from the hospital.

Results
Among the 87 patients discharged for long-term nursing care in an institution amputation was performed at TK level in 19 cases, AK in 45 and BK in 23 cases. Prosthetic fitting was generally achieved in 14 per cent (12/87) of cases, whereas the remainder were either wheelchair bound or bedridden. Patients amputated at the shank or through the knee did better than those amputated at the thigh (Table 1).

Discharge to a nursing institution was necessary for 45 patients who had been living in their own surroundings preoperatively, and 80 per cent (36/45) of these patients were wheelchair bound or bedridden. Among those obtaining a walking capacity 9 out of 12 had preoperatively lived in their own home. Only half of the patients discharged to a nursing institution with a prosthesis were able to use the prosthesis outdoors.

Table 1 Results of prosthetic fitting in patients discharged to institutions for long-term nursing care.

Level	Prosthetic gait	Wheelchair	Total
TK	4 (21%)	15	19
AK	4 (9%)	41	45
BK	4 (17%)	19	23
Total	12 (14%)	75	87

Table 2 Result of prosthetic fitting in patients discharged to own home or a temporary rehabilitation institution.

Level	Prosthetic gait			Total
	Outdoors	Indoors	Wheelchair	
TK	20 (69%)	8 (28%)	1 (3%)	29
AK	29 (41%)	14 (20%)	28 (39%)	71
BK	56 (72%)	9 (11%)	13 (17%)	78
Total	105 (59%)	31 (17%)	42 (24%)	178

Among 178 patients discharged to their own home or a temporary rehabilitation institution every fourth patient was finally bound to a wheelchair (Table 2). Hardly any of the TK amputees were wheelchair bound and 69 per cent achieved an outdoor walking capacity. Nearly three quarters of the BK amputees obtained an outdoor walking capacity, but as many as 17 per cent were wheelchair bound. The poorest results were encountered after AK amputations, as more than every third patient was wheelchair bound and less than half of the patients were able to walk outdoors.

Discussion

Gangrene of the lower limb with major amputation is often followed by a high primary mortality (Jensen, 1982) due to the generalized toxic physiological effect and many amputations are consequently undertaken as life saving procedures. This is especially the case among patients who are already in need of long-term nursing care. The loss of a limb in elderly patients often leads to dependence on other people and often to discharge to an institution for long-term nursing. This was experienced in nearly every fifth patient of those previously living independently at home. The majority of these patients were wheelchair bound or bedridden irrespective of the level of amputation. Discharge to long-term nursing care without a walking capacity is definitely to be considered as a poor result, although life is saved.

Among patients returning to their own home the goal of the amputation surgery should be to make the patient ambulatory with a prosthesis. This was achieved in 76 per cent of patients in this series. A striking feature of these results show, however, that the statement of preserving the knee joint at any price (Pedersen, 1968)

seems to be no longer valid, as patients with TK amputations generally did better than BK amputees and the majority of AK amputees failed to achieve prosthetic gait.

The results of AK amputations are fairly consistent with previous reports (Chapman et al, 1959; Burgess et al, 1971; Christensen, 1976), but better than a number of others (Warren and Kihn 1968; Hierton and James, 1973; Robinson, 1976). The success rate of BK amputations with prosthetic fitting in 83 per cent of cases also correlates with previous reports (Smith, 1956; Burgess et al, 1971; Chilvers et, 1971), although Hierton and James (1973) claimed prosthetic walking in 66 per cent and Holstein et al (1979) in half of the cases only.

The high success rate following TK amputations has been pointed out before (Early, 1968; Howard et al, 1969, Chilvers et al, 1971; Newcombe and Marcuson 1972), but the general opinion is still to select the BK amputation level whenever possible. This might be explained by the high technical development of BK prosthetics and numerous theoretical and biomechanical advantages of the BK level as well as the cosmetic problems experienced with the TK prosthesis. It is, however, hoped that problems related to the manufacture of TK prostheses and the inborn traditional aversion might be overcome with this issue of Prosthetics and Orthotics International.

The explanation for the high success rate of TK prosthetics is probably due to the undisturbed strength of the hip and thigh muscles, the end-bearing capacity of the stump and a feeling of stability and tightness of the socket. Another explanation might be that the prosthesis can easily be supplied with a knee lock in case the patient demonstrates instability or incapacity in walking with a mobile knee joint. This is in contrast to BK prosthetics, where a preliminary PTB or comparable prosthesis has to be exchanged with a conventional prosthesis with a knee lock in a similar situation. In such circumstances the physiotherapist and the prosthetist might often press the patient to continue with the prosthesis and elderly patients are not likely to disappoint their therapists.

Unfortunately these statements are purely founded on qualified guessing, as this retrospective series does not give sufficient information about these problems. It has, however, previously been pointed out (Jensen et

al, 1982) that a BK amputation cannot be converted to a TK amputation in cases of extensive skin necrosis or infection.

Based on these considerations it is suggested that the TK level of amputation should be selected in all possible instances as an alternative to an AK amputation, as the prosthetic fitting is highly superior. It is also suggested that the TK level should be considered as an alternative to any BK amputation in all old and probably feeble patients if the postoperative fitting might be problematic, as such patients are more likely to be able to walk on an artificial, although stiff, limb after TK amputation. In all circumstances, where the perfusion of the amputation area is doubtful evaluation of the possibilities of breakdown of the BK stump should always be taken into consideration in favour of a TK amputation. Eventually the TK amputation should be considered also in patients demanding a wheelchair existence, especially in risk of contralateral amputation, as stability in the wheelchair is absolutely superior as compared to an AK amputation because of the long and strong stump.

Acknowledgements

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Calendar of events

National Centre for Training and Education in Prosthetics and Orthotics

Short-Term Courses and Seminars 1983–84

NC 704 Walking for the Paraplegic and Tetraplegic; 5 October, 1983.
NC 705 Pediatric Footwear; 22 February, 1984.
NC 706 Wheelchairs; 27–28 March, 1984.

Courses for Physicians and Surgeons

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

Courses for Physicians, Surgeons and Therapists

NC 503 Introductory Biomechanics, Prosthetics and Orthotics; 31 October–4 November, 1983.
NC 504 Lower Limb Orthotics; 21–25 November, 1983.
NC 505 Lower Limb Prosthetics; 16–20 January, 1984.
NC 502 Upper Limb Prosthetics and Orthotics; 23–27 January, 1984.
NC 501 Functional Electrical Stimulation (Peroneal Brace); 12–15 March, 1984.
NC 506 Fracture Bracing; 4–6 April, 1984.

Courses for Prosthetists

NC 211 Patellar-Tendon-Bearing Prosthetics (Cuff and Supracondylar Suspension); 12–23 September, 1983.
NC 212 Hip Disarticulation Prosthetics; 28 November–9 December, 1983.
NC 205 Above Knee Prosthetics; 27 February–9 March 1984.

Courses for Orthotists

NC 203 Knee-Ankle-Foot and Hip-Knee-Ankle-Foot Orthotics; 12–23 September, 1983.
NC 207 Spinal Orthotics; 7–18 November, 1983.
NC 213 Ankle-Foot Orthotics (Conventional and Plastic); 30 January–10 February, 1984.

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

5–7 October, 1983

11 Simposium de Inginieria Biomadica, Madrid, Spain.
Information: 11 Simposium de Ingenieria Biomadica, E.T.S.I. Telecomunicacion, Ciudad Universitaria, Madrid 3, Spain.

5–9 October, 1983

1st European Congress on Scoliosis and Kyphosis, Dubrovnik, Yugoslavia.
Information: "ATLAS" Congress Department, Zrinjevac 17, YU-41000, Zagreb, Yugoslavia.

9–13 October, 1983

7th International Congress of Electromyography, Munich, West Germany.
Information: Prof. D. A. Struppler, Neurologische Klinik Der Technischen Universitat, Mohlstrasse 28, 8000 Munchen 80, West Germany.

17–21 October, 1983

Amputee Rehabilitation for Therapists, Manchester, England.
Information: Mrs Hindley, Rehabilitation Unit, Withington Hospital, Manchester M20 8LB, England.

22–27 October, 1983

American Academy of Pediatrics Annual Meeting, San Francisco, California.
Information: American Academy of Pediatrics, 1801 Hinman Avenue, Evanston, IL 60204.

25–30 October, 1983

American Orthotic and Prosthetic Association (AOPA) National Assembly, Hyatt Regency, Phoenix, Arizona.
Information: Mrs. Sonja I. McCamley, AOPA, 717 Pendleton Street, Alexandria, VA 22314, U.S.A.

7–10 November, 1983

VII Congress Brasileiro de Engenharia Biomedica, Brazil.
Information: EEL-UFSC, P.O. Box 476, Florianopolis-SC88000, Brazil.

13–18 November, 1983

2nd International Symposium on Design for Disabled Persons, Tel Aviv, Israel.
Information: Dr. E. Chigier, KENES, P.O.B. 29784, Tel Aviv 61297, Israel.

13–20 November, 1983

3rd International Seminar on The Treatment of Rheumatic Diseases, Tel Aviv and Jerusalem, Israel.
Information: The Secretariat, Rheumatology, PO Box 3054, Tel Aviv 61030, Israel.

18–20 November, 1983

Mechanical Therapy of The Lumber Spine, Sutton Coalfield, West Midlands, England.
Information: Mr. M. G. Robinson MCSP, 92 Lindridge Road, Whitehouse Common, Sutton Coalfield, West Midlands B75 6HJ, England.

30 November–2 December, 1983

4th International Symposium on Academic Orthopaedic Manpower, Pennsylvania, USA.
Information: Robert B. Greer III, MD, Symposium Co-Chairman, Milton S. Hershey Medical Center, PO Box 850, Hershey, Pennsylvania 17033, USA.

1984

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

January, 1984

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

26–28 January, 1984

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