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The iron hand from Slovenia

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Abstract

The iron hand prosthesis now in the custody of the Rehabilitation Institute Ljubljana, was excavated some 80 years ago in the ruins of the Vransko castle. The hand, its form and function are described. It was manufactured somewhere in Europe between the years 1500–1650. The owner, probably one of the local nobles, has remained unknown.

Introduction

In 1907 an ancient prosthesis was found in a walled-in niche while pulling down the old castle at Vransko (Fig. 1). No bones or weapons were found beside it (Stracker, 1917). It accidently found its way into a private collection of antiquities owned by J. Sadnikar, a veterinary surgeon from Kamnik, and from there to the Rehabilitation Institute of Ljubljana.

A search has been conducted for the original owner of the prosthesis among the feudal lords in the neighbourhood of Vransko where there are a number of castles (Orožen, 1880).

The search, however, was futile; no clues or records could be found in the local chronicles. The nearest church archives were burned during the second World War, whereas the castles themselves were pillaged during the peasant uprisings in 1635 and 1650.

Amputation and stump

From a study of the prosthesis, Grobelnik (1990) believes that the amputation probably occurred as follows: the cut started in the middle of the first thumb phalanx, proceeded to the upper third of the metacarpal index bone, and then passed obliquely downwards through the other metacarpal bones to the pisiform axis of the right hand. The bleeding could not have been substantial and the injured man survived the accident. The resulting stump was suitable for the wearing of the iron prosthesis. The wrist remained movable, the thumb stump fitting well into the prosthesis and providing at least a partial control over it.

The amputation was probably caused by a sword while the knight's hand was closed into a fist, possibly holding reins, a spear or a flag pole.

The armourer who manufactured this prothesis quite ingeniously profited from the shape of the stump by shifting the entire mechanism of the prosthesis to its lateral area, thus gaining room for the stump of the thumb.

The amputee probably wrapped the stump into a piece of cloth or a bandage. He must have made good use of the prosthesis because the bandage thoroughly soaked with sweat

Fig. 1. Vransko, the place where the iron hand was found.

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Fig. 2. The iron hand, in opened position.

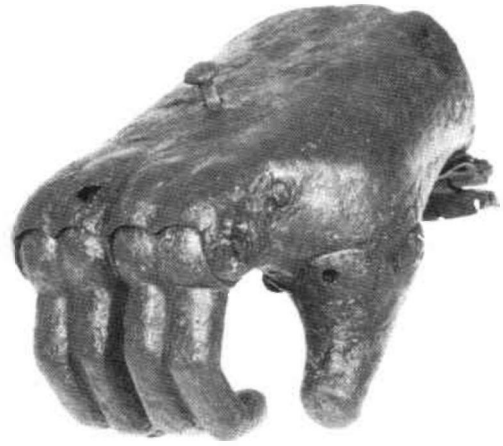

Fig. 3. The iron hand, in closed position.

would be the cause of the verdigris that can even now be observed in the prosthetic socket.

Structure of the prosthesis

The prosthesis, weighing 795 g, was made to replace a male right hand (Figs. 2 and 3). It roughly imitates the shape of the human hand. The palm storing the mechanism is somewhat larger. Compared to the palm, the fingers are thinner and semiflexed in the 1st and 2nd interphalangeal joints. The manufacturer went so far as to indicate the nails.

The thumb is shorter, rigid, and placed in opposition to the palm, which is most important for function. It enables a cylindrical grasp which would have made it possible for the amputee to hold a sword, a spear, reins, as well as a cup (then made of tin), and tools (Fig. 4).

The surface of the prosthesis is somewhat rough, the rust giving it a brownish colour. In the palm below the 4th and 5th finger, on the dorsum of the hand below the 4th finger, and on the thumb it is slightly corroded (perhaps from use). On the inside, in the area of the socket some verdigris can be noticed.

A longitudinal embossment runs along the middle of the palm, most probably facilitating a better grasp. In the middle of the dorsum a button-powered lever locks and unlocks the mechanism for moving the fingers.

On the volar side of the prosthesis a perforated hinged joint seems to have served to fasten possibly a leather butt onto the forearm. The material of which the butt was actually made and the way in which it was adjusted onto the forearm can only be guessed at. It might have been fixed in such a way as to facilitate mobility of the hand in the wrist, thus

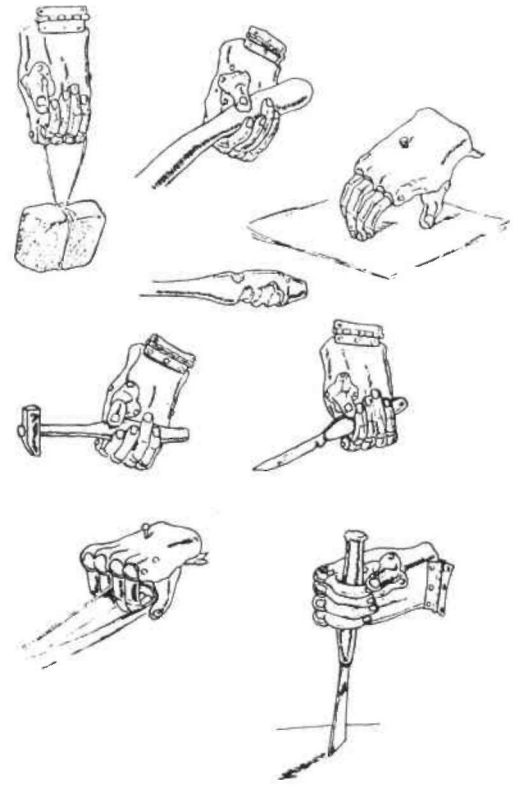

Fig. 4. Possibilities of the use of the hand from Vransko.

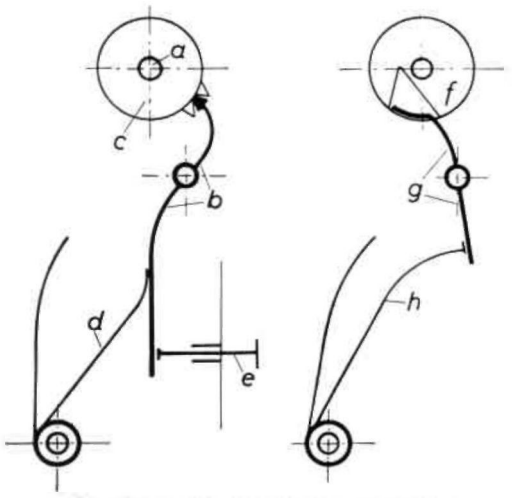

Fig. 5. Function of blocking mechanism.
The fingers being contracted around axis "a", the tip of lever "b" engages in the tooth on joint "c". The pressure of spring "d" prevents the sliding of the lever tip from the groove. By pushing button "e" on the dorsum of the prosthesis the lever is released and the fingers spring to the extended position.
As for the reverse mechanism the finger joint is provided with wheel "f" which is exposed to the action of lever "g". When the fingers contract, the wheel turns lever "g" around, compressing spring "h". Once the blocking mechanism is released, the spring presses the lever onto the wheel, and the fingers return to the initial position.

contributing to a better function of the prosthesis.

The fingers (the thumb is rigid) move in pairs in three steps but not coming into full contact with the tip of the thumb and the palm of the prosthesis.

Functioning of the mechanism

Even today the mechanism functions faultlessly. The wear of the teeth suggests that the prosthesis was well used. The mechanism consists of springs, cogwheels, and crank drives by which the fingers can be passively contracted or extended.

The mechanism fulfils two functions (Fig. 5):

- it stops the fingers in a desired contracted position in one of three steps,
- it releases the crank drives to let the fingers return to the initial position.

On the margin of the palm where the joint appears in a normal human hand, hinges are positioned. It is now hard to say what specific purpose the hinges were intended for but the rest of the construction seems to indicate that the designer of this iron hand also tackled the problem of the mobility of the hand in relation to the forearm.

At first sight such a metal hand might seem easy to make. However, a close study of the finger-moving mechanism shows that the problem is all but simple. It is similar (Fig. 6) to the original drawing of Paré (1840).

The iron sheet (approximately 1 mm) seems to have been made of two layers rolled together in a hot state or else "welded" together by forging.

The hand is made of several pieces joined by means of rivets. The holes for the rivets were pierced in a hot state and cold rivets then driven in. The holes then contracted on cooling, thus tightly gripping the rivets. It is possible that the rivet shank was notched to reduce the possibility of becoming loose.

A metallographic analysis of the sample (Pelhan, 1972) shows that the material of the hand is soft iron with a high content of oxidizing slag inclusions. The basic structure of soft iron is pratically free of carbon. As obvious from the metallographic specimens, the material used in manufacturing the prosthesis was either processed steel or soft iron made by carbon elimination. In either case the iron was forged

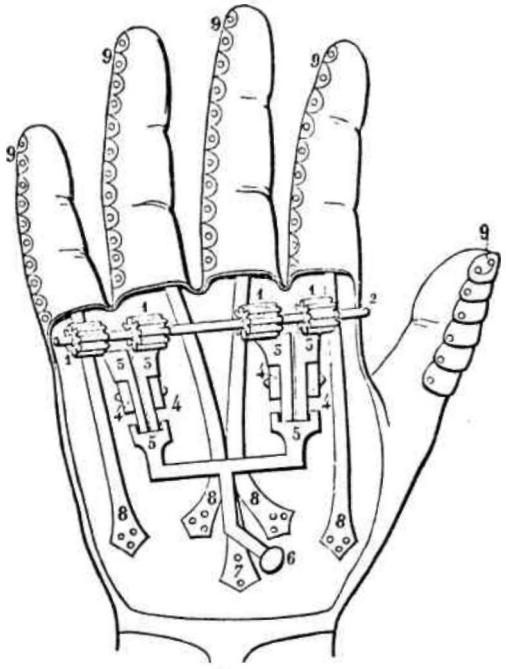

Fig. 6. Scheme of the artificial hand—from Paré 1840.

or rolled so as to remove the largest possible quantity of slag.

Discussion and conclusion

The noblemen of those times doubtlessly felt ashamed of being maimed. They tried to camouflage their condition as best they could. At the same time they wanted the aid to serve them in such vital activities as eating, drinking, use of weapons, and riding. The question is who in fact manufactured these prostheses. It could have been manufacturers of cuirasses, well trained as to technical construction, armourers or, to cite Paré (1840) with respect to "Le Petit Lorraine", locksmiths.

It would be interesting to know when individual prostheses were made. It is possible to fix the period of Gotz's hand (1505–1508); we also know one of the manufacturers by name, one "Le Petit Lorraine". These two hands and the one from Ruppin probably served as models to all other manufacturers, which is deduced from the fact that their technical solutions resemble one another, even though some are rather simple and others more sophisticated. Gotz's hand, however, represents the apogee of the technical knowledge and skill of its time both in its appearance and the principles of the finger-moving mechanism. It is not improbable (Putti, 1924) that all of these hands were invented by the same man or, at least follow the same basic idea that led several inventors to similar final products.

The advantage of the above hand over the others lies in its having a strong and immobile thumb placed in opposition to the palm. Such a thumb is optimal, offering firm support to the other fingers. A mobile thumb would of course come closer to a normal hand but it would require an additional mechanism, which implies further complications in its functioning which is already quite complicated.

The Slovenian hand could not have a mobile thumb because of the form of the stump. A most useful thumb stump was preserved as a result of which the mechanism had to be shifted to the lateral area of the prosthesis. The portion of the thumb that remained intact and a moveable wrist must have contributed a lot to the effective application of the prosthesis.

In his study on the iron hand, Stracker (1917) expressed doubts as to the presumption that the prosthesis could only have served a knight. In his belief it dates back to the 17th century. According to his study, its owner used it also for various other menial i.e. "unknightly" tasks.

We cannot but disagree with his arguments since the then "working man" would neither have the opportunity nor the money to purchase it, and in fact had no need for such a hand. We therefore insist on the presumption that the prosthesis belonged to a nobleman who must have lived some time between 1500 and 1635 when the castles of the Vransko area were under intense attack by robbers.

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A standardised trans-tibial amputation method following chronic occlusive arterial disease

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Abstract

The histo- and biochemical parameters of leg muscles from patients with chronic occlusive arterial disease were examined. The outcome of these tests indicated that it is not possible visually to determine the amputation level accurately at the time of surgery. These test results therefore encouraged the authors to develop a standardised surgical procedure for trans-tibial amputations. With this standardised technique specific musculature is resected to assure that no pathological tissues remain. This surgical prophylaxis is meant to prevent the development of gas gangrene and thus to obtain primary healing. Eighty-six trans-tibial amputations were performed and in 93% of these the knee joint was preserved.

Problems and goals

Visual muscle assessment at the time of amputation surgery and the actual histopathological and biochemical test results of the same tissues are seldom identical (Brückner, 1983; Geissler and Brückner, 1985; Brückner *et al.*, 1986). A high failure rate occurs when the decision to resect impaired muscle tissues is based only on the surgeons' visual judgement during surgery. The author therefore considered removing all musculature not required to cover the stump end. This practice, combined with clinical observations and surgical experience over a 16 year period, encouraged them to standardise the trans-tibial amputation technique as practised by Burgess *et al.* (1971) thus avoiding subjective errors which could result from merely visual muscle assessment during surgery. This surgical standardisation provides to surgeons a more effective and reliable trans-tibial amputation method which is indicated for patients who have chronic occlusive arterial disease.

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Surgical technique

The procedure to create anterior and posterior flaps is identical to the Burgess *et al.* (1971) original technique. The level of the anterior skin incision is 1–2 cm below the tibial tuberosity.

After the division of tibia and fibula the major vessels are closed with double ligatures. One should note that the major vessels seldom show heavy bleeding. The n. tibialis and the n. peroneus are traced proximally and cleanly resected. The end of the tibial remnant is bevelled. Then the m. tibialis anterior as well as the remaining fibula are totally removed. The fibular muscle group (m. extensor digitorus longus and m. fibularis longus), the m. flexor hallucis longus, m. tibialis posterior, m. popiteus and the m. soleus are resected as far proximally to the tibial division as possible. Thus only the m. gastrocnemius medialis and lateralis remain. The m. gastrocnemius medialis, which very rarely shows ischaemic pathology, is used to cover the end of the tibia by folding it anterolaterally.

To avoid haematoma and also pad the lateral aspect of the stump, the loose end of the m. gastrocnemius medialis is inserted into the cavity created by the excision of the m. tibialis

anterior and the fibula. If, however, complete coverage with the m. gastrocnemius medialis is not entirely possible, then a part of the m. gastrocnemius lateralis has to be sutured into place at the former origin of the m. tibialis anterior. The latter procedure almost always results, due to the shifting of the muscles, in unnecessary excess muscle tissue of the m. gastrocnemius lateralis. In the interest of good stump formation and to reduce unnecessary muscle bulk, which would require extra circulation, this excess muscle has to be reduced. The musculature is fixed to the tibial periosteum using absorbing sutures. Special care has to be taken to avoid the formation of any cavities.

To avoid haematoma a Rendon drain is inserted for 2–3 days. The skin closure is achieved with 3–4 equally spaced atraumatical stitches and completed with steri-strips to avoid possible wound complications.

The removal of any musculature with a poor blood supply is indicated, especially the m. soleus. At this point one should note, that the m. soleus is not, in most cases, histopathologically and biochemically affected. The muscle may, however, cause problems through its thrombosis-prone venous plexus. The removal, therefore, constitutes an effective prophylaxis against gas gangrene and with it primary closure of the wound is possible.

The surgical wound is covered with sterile gauze pads. Stump and thigh are padded with resilient bandages. An elastic bandage is lightly applied to prevent oedema and to avoid cirulatory restriction. Everything is then covered with a paper bandage. This paper bandage separates the elastic bandage from the then applied posterior plaster splint, which is put into place to prevent a possible knee flexion contracture. For stump control and to avoid pressure areas, dressing changes occur one day postoperatively and daily thereafter up to 4 days, in some cases longer. After that period dressing changes are done as individually required (Brückner, 1986; Brückner, in press). Baumgartner *et al.* (1989) states that the standardised trans-tibial amputation technique primarily produces short stumps, thus reducing stump leverage. The average stump length produced by the author measures 8–9.5 cm. This length permits problem free rehabilitation and permits total contact socket fitting.

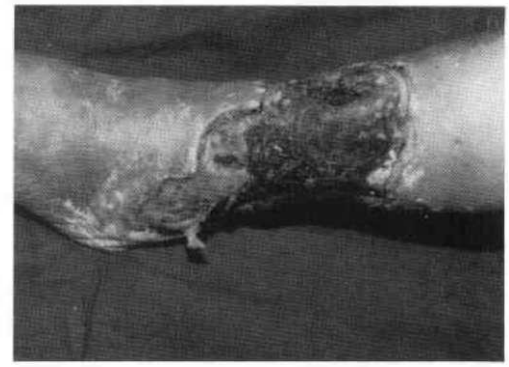

Fig. 1. Patient: R. J.; 63 years Ulceration at the left lower leg. Chronic occlusive arterial disease.

Stump healing

Some 86 trans-tibial amputations were performed with this standardised technique. The knee joint was preserved in 93% of the cases. While previously in 128 trans-tibial amputations, performed according to Burgess *et al.* (1971) (from April 1975 to April 1982), the knee joint was preserved in only 83% of the cases (Brückner, 1988).

Rehabilitation

The results of this procedure in relation to rehabilitation outcome have been assessed by questionnaire in 38 patients 2 to 10 years after they experienced standardised trans-tibial amputation. These are shown in Tables 1 and 2.

Discussion

Sanderson *et al.* (1975) and the author observed that the macroscopic assessment of the viability of muscle tissue during surgery is very difficult. This takes on a special meaning as amputation surgery in certain geographic

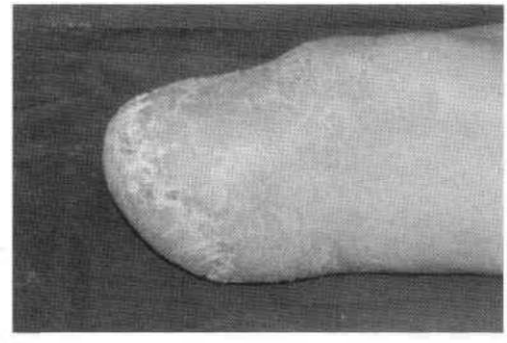

Fig. 2. The same patient, 4 weeks after the operation. The length of the stump is 90 mm.

Tale 1. Prosthetic rehabilitation.

Prosthetic consideration	Patients
Supply of modified KBM prosthesis	94.7%
Early use of prosthesis following amputation	66.0%
Use of the prosthesis	
– daily, with short breaks	41.0%
– daily, but only for some hours	27.8%
– more than once every week	13.9%
Independent donning and doffing of the prosthesis	
– without assistance	71.1%
– with assistance	28.9%
Walking with prosthesis and with a maximum of one walking aid	78.9%
Security at slow pace	73.7%
Walking upstairs and downstairs without assistance	71.1%

areas is often performed by junior residents and perhaps even at the end of the operating schedule. Therefore, in an attempt to reduce the possibility of subjective error by visually assessing muscle tissues during surgery and to establish a better necrosis, specifically gas gangrene phrophylaxis by taking histological and biochemical results into account, the author revised and standardised the Burgesss *et al.* (1971) original surgical procedure for trans-tibial amputations. In this manner, all surgeons, including colleagues who do not have a wide experience in the assessment of musculature, can perform these amputations. This standardised method is part of a programme which also includes postoperative care as well as rehabilitation.

When strandardising the surgical procedure, the removal of muscle tissue and the provision of sufficient stump coverage have to be viewed in perspective. The m. tibialis anterior is totally excised, therefore the remaining part of the fibula must also be removed to avoid the formation of a cavity and to avoid creating potential pressure points in the socket of the prosthesis which will in the future be fitted.

The advantage of this intensive muscle reduction is that muscle tissues which cannot be conclusively assessed and could be rather ischaemic, will not remain in the stump. One could also hypothesise, that, whatever blood supply there is will be sufficient nutrient for the reduced muscle bulk in the stump.

The folding of the entire posterior skin-muscle flap over the end of the tibia, and the suturing of the m. gastrocnemius medialis result in the application of a tensile force to the remaining segment of this muscle. This according to Goldspink (1977), counteracts muscle atrophy and loss of tissue, protein, and according to Hansen-Leth (1982), avoids the formation of arterio-venous shunts, which may accompany secondary reduction of circulation.

According to the author's experiences, the meticulous removal of ischaemic tissue (standardised surgical procedure) does not

Table 2. Occupational rehabilitation.

Pre-amputation	Classification	Post-amputation
28.9%	Working people	15.8%
5.3%	disability pensioner	10.5%
65.8%	old-age pensioner	73.7%
100%		100%

increase the risk of gas gangrene infection. In 2 cases of all the trans-tibial amputations (1975–1991) where such complications occurred, the surgical procedure deviated from the standardised procedure. Both cases occurred in 1975 and 1976 when efforts to improve trans-tibial amputations were in the starting phase.

Gas gangrene prophylaxis as demanded in Chirugerie der Infektionen (1981), the removal of all necrotic and suspected necrotic tissue, is strictly adhered to in the prescribed surgical technique. It is believed that the advantage over the original procedure by Burgess *et al.* (1971) is the elimination of the subjective assessment of the musculature during the operation.

Gas gangrene prophylaxis also requires, that preoperatively on the ward, gangrenous regions are covered, so that there will be no contact with these infected areas once the patient is in the operating room.

Of major importance is the lumbar anaesthesia which is almost always used with its vasodilatory effect. It is also helpful that, with this anaesthetic, patients experience no additional respiratory restrictions postoperatively. Since there is always suspicion of an insufficient oxygen supply to the stump, there is at least sufficient oxygen breathing postsurgically.

Another decisive factor which avoids jeopardising the stump's circulation is the technique in which the immediate postoperative stump bandage is applied. This bandage, carefully applied, must supply sufficient tension to minimise stump oedema, while simultaneously avoiding circulatory restriction and provide a stump rest position without causing knee flexion. Special care is required to avoid pressure spots on the already compromised stump circulation. Furthermore, stump positioning shall be neutral, neither too high nor too low.

Usually the prophylactic antibiotic treatments that several authors demand are not administered. Also, wound spray, which results in an airtight coating, must not be used for post-operative dressings.

The first dresssing change is done on day one postsurgically to assess the condition of the wound and to relieve any possible pressure spots. To attempt a first dressing change after several days, as several authors recommended, is considered risky. Dressing changes are always done by the surgeon who performed the amputation. Further dressing changes are done daily for 4 consecutive days. Thereafter dressing changes depend on individual conditions. Indirect wound control (by means of body temperature, smell, evidence of pain)

Table 3. Comparative results of trans-tibial amputation procedures.

Trans-tibial amputation procedure, Burgess:			
1970	Sorensen	82%	
1970	Jones *et al.*	71%	21 amputations
1971	Burgess *et al.*	92% (Diab.mell.)	91 amputations
1971	Burgess *et al.*	88.5% (Art.scl.)	68 amputations
1974	Kolind-Sorensen	63%	
1975	Murdoch	90%	29 amputations
1975	King *et al.*	89%	28 amputations
1977	Termansen	73%	88 amputations
1977	Couch *et al.*	78%	119 amputations
1978	Tabatabai *et al.*	94%	17 amputations
1981	Persson *et al.*	75%	
1981	Vinz *et al.*	80.5%	36 amputations
Standardised trans-tibial amputation procedure, Brückner:			
1986	Brückner *et al.*	95.5%	44 amputations
1989	Putziger *et al.*	83%	29 amputations

without changing the dressing, as recommended by Persson *et al.* (1981) is not accepted. In this context the author concurs with the opinions of Morscher (1978), Tabatabai *et al.* (1978) and Helmig (1978) who state that trans-tibial amputations for chronic occlusive arterial disease belong in the hands of the experienced surgeon.

Every surgically active colleague who has been involved in trans-tibial amputations knows, that the removal of all the musculature except the medial head and small part of the lateral head of the m. gastrocnemius, while still producing a stump that has functional and weight bearing properties, requires experience.

Close liaison with the Department of Internal Medicine is necessary. Special consideration has to be given to prosthetic fitting. Truly optimal results, however, will only be achieved through individual physiotherapy treatments and controlled gait training.

Statistical comparison

With the introduction of this standardised surgical procedure (Brückner, 1986) it was possible to preserve the knee joint in 93% of the 86 cases.

Comparative results of other authors (in chronological order) are shown in Table 3. These results indicate that valuable results can be obtained with this standardised amputation procedure by Brückner.

Conclusion

One can conclude that the decision not to amputate below the knee in patients with chronic occlusive arterial disease (class IV Fontain) is unjustified. It is also possible by strictly adhering to the standardised technique and the described follow-up treatment immediately to close the surgical wound, thus avoiding a broad scar. Amputees who have mature, functional and weight bearing stumps demonstrate, regardless of age, satisfactory rehabilitation results.

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Level of lower limb amputation in relation to etiology: an epidemiological study

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Abstract

The Danish Amputation Register and the nationwide National Patient Register are presented.

Based upon the code numbers in the WHO classification system (ICD), 4 etiology groups i.e. vascular insufficiency, diabetes mellitus, malignant neoplasma and trauma were extracted. The purpose was to analyse the relationship between level of amputation (i.e. foot, below-knee, through-knee, above-knee and hip) and etiology (cause of amputation). The material represents all such amputations in Denmark during the period 1978 to 1989 (n=25.767).

The number of amputations because of vascular insufficiency with and without diabetes mellitus decreased over the period studied. The number of tumour and trauma amputations seemed unchanged.

There was a significant reduction in the number of amputations at proximal levels (above-knee) for vascular insufficiency with and without diabetes mellitus and in the trauma group. No such change was found regarding tumour amputations. There was a characteristic pattern in the distribution of level respectively of etiological factors for each etiology group and for each level of amputation.

Introduction

The majority of studies analysing the epidemiology of lower limb amputations describe the distribution of level for the separate etiology groups (e.g. vascular insufficiency, trauma or neoplasm). In some studies the distribution of level is related to a total amputation population without distinguishing separate etiologies (Glattly, 1964; Kay and Newman, 1975; Kald *et al.*, 1989). A number of studies (Hansson, 1964; Kay and Newman, 1975; Pohjolainen and Alaranta, 1989) show considerable differences in the distribution of etiology. No studies have analysed the distribution of etiology at each individual level of amputation. Seen from an epidemiological point of view, it is interesting to analyse the relationship between cause of lower limb amputation and the choice of level on a very large material with national coverage for the years 1978 to 1989. Further the changes observed during the period under study are discussed.

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Material and methods

The Danish Amputation Register (DAR) was established in 1972 for the purpose of collecting and analysing data on upper and lower limb amputations in Denmark (Ebskov, 1986). Since 1978 information was also available in the National Patient Register (NPR). The NPR contains details on all patients admitted to Danish somatic hospitals, thus ensuring national coverage and permitting an analysis of the entire Danish in-patient population.

The present study is based upon NPR data from 1978 to 1989. Diagnoses are recorded according to WHO's International Classification of Diseases (ICD). In the present study it was decided to include the 4 etiology groups: vascular insufficiency, diabetes related amputations; malignant bone and soft tissue tumour, and trauma. It may be mentioned that embolism and thrombosis as well as Raynaud's

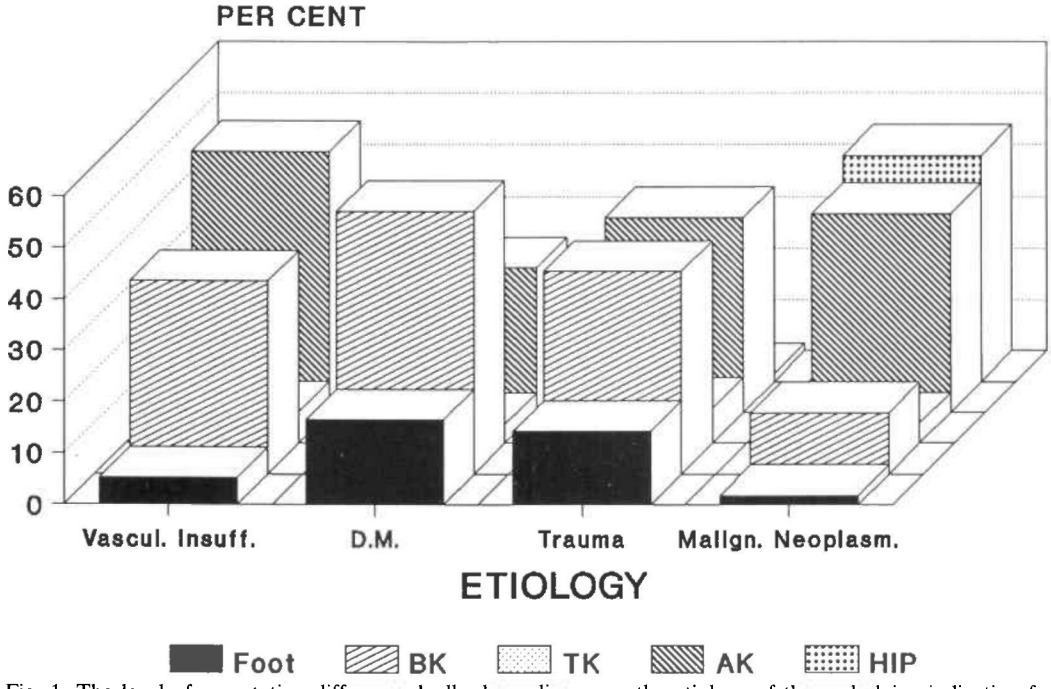

Fig. 1. The level of amputation differs markedly depending upon the etiology of the underlying indication for amputation.

and Buerger's diseases are included in the vascular insufficiency group.

The remaining relatively rare etiology groups are excluded pseudoarthrosis, benign neoplasm, skin cancer, gangraena emfysematosa, metastasis, chronical venous ulceration, osteomyelitis etc.)

Operations (level) are recorded according to the Danish National Health Board and distributed in 5 level-groups (foot exclusive of toes, below-knee (BK), through-knee (TK), above-knee (AK) and hip (including hemipelvectomy and disarticulation of the hip.

Results

During the period 1978 to 1989, 17,548 lower limb amputations were performed because of non-diabetic vascular insufficiency (arteriosclerosis/gangrene), 6,839 amputations on diabetic patients, 1,095 amputations as a direct consequence of trauma (either direct traumatic amputation or degloving/crushing of the limb) and 285 amputations because of malignant soft tissue or bone tumours.

Figure 1 shows the distribution of level for the etiology groups in the total material.

Figure 2 shows the changes in distribution of level from 1978–80 to 1987–89. Some significant changes are observed i.e. reduction of the proximal levels and a relative increase of the distal levels for the vascular insufficiency group, the diabetes group and in the trauma group. The neoplasm group seems to be unchanged.

The total number of amputations in 1978–80 related to the number in 1987–89 shows no significant changes in the trauma or tumour amputations. The number of diabetic amputations and the number of vascular insufficiency (non-diabetic) show a significant decrease in 1978–80 to 1987–89.

Figure 3 shows the etiology distribution at different level of amputation. At foot level diabetic amputations represent the largest group with 52%; at increasingly higher levels diabetic amputations show a steady decrease until it reaches 5% in the hemipelvectomy group. The vascular insufficiency group dominates BK, TK and especially the AK group, where it constitutes 78%. The neoplasm amputations show another pattern with relatively small fractions from foot to AK, in these groups equalling less than 1%, whereas in

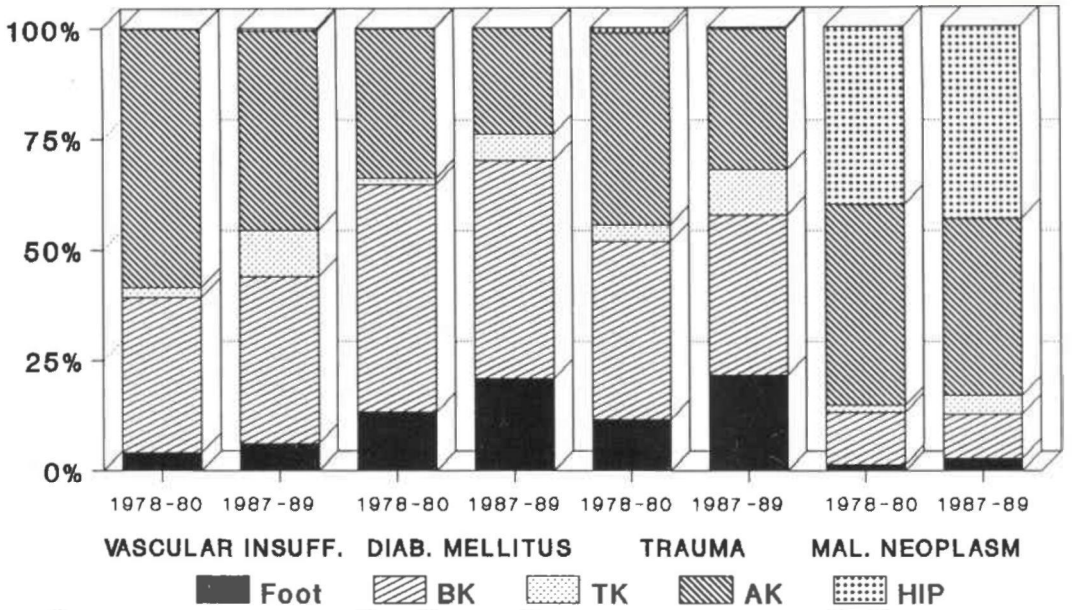

Fig. 2. For the four major causes of lower limb amputation, the distribution of amputation levels is compared for the triennium 1978–1980 and 1987–1989 respectively. In the tumour group no major change is noted. In the remaining three groups there is a marked tendency towards more conservative amputation.

the hemipelvectomy group it constitutes 53%. The traumatic amputations again have another pattern, with fractions equalling about 6% in the foot and the hemipelvectomy groups and for the remaining levels about 4%.

Discussion

The relationship between level of amputation and cause of amputation (etiology) is described based upon a large number of amputations and significant changes are found during the period analysed in the distribution of level for vascular insufficiency, diabetes and trauma. Further the etiology distribution is expounded for different levels, which is a new way to display the epidemiological characteristic of the amputation material.

The overall etiological distribution confirms the well-known fact that lower limb amputation because of vascular insufficiency with or without diabetes mellitus is the quantitatively dominant group. Comparison of the etiology distribution with earlier studies is complicated by differences in content and arrangement of the material. This problem is especially pronounced in regard to the diabetic group where toe amputations are frequent (about 20% of the diabetic amputations in 1989) but of less practical importance. In the material reported here toe amputations are excluded and the diabetic amputations account for 26%, if included (in all the etiology groups) this figure is virtually unchanged. The proportion of diabetic amputations in Denmark seems to be significantly smaller than earlier reported (approximately 40% or more) (Pohjolainen and Alaranta, 1988; Liedberg and Persson, 1983; Tan *et al.*, 1983; Hansson, 1964).

The percentage of traumatic amputations seems to be significantly smaller than in former times (Hansson, 1964) where the typical percentage, in the period about 1940 to 1960, was about 20–30%. Pohjolainen and Alaranta (1988) describe a significant decrease in the number of amputations due to trauma (from 12% in 1970 to 2% in 1985). The reason for the decrease can probably be explained by improved industrial and traffic safety and advances in replantation surgery (Chen and Zeng, 1983; Østrup and Vilkki, 1986). In the present study no significant changes in the number of traumatic amputations were observed.

Also tumour amputation seems to be comparatively infrequent in relation to earlier studies although unclear definition of this amputation group makes it impossible to perform comparison of the results. During the

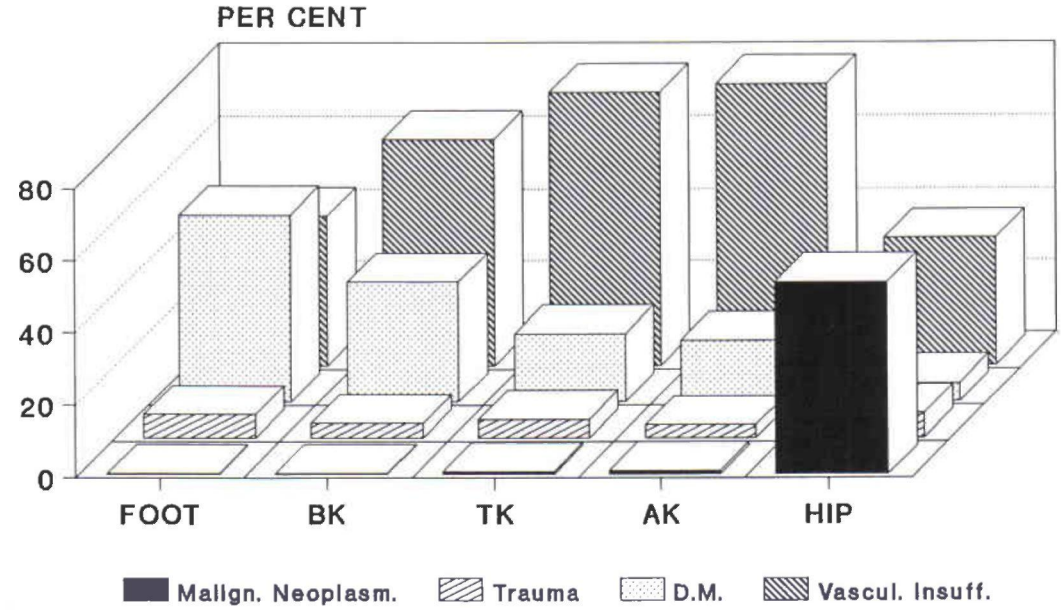

Fig. 3. The distribution of the four major causes of amputation varies markedly with level of amputation. From foot to AK levels the relative share of diabetic gangrene decreases, whereas the share of arteriosclerotic gangrene increases. Malignant tumour is dominant at the hip level (hip disarticulation and hemipelvectomy), but scarcely represented at all levels distal to the hip.

period 1978 to 1989 no decrease in the number of amputations as a consequence of malignant soft tissue and bone tumours was observed, in spite of attempts to optimise limb-preserving surgery in this group (Alho, 1987; Nambisan and Karakousis, 1987; Potter *et al.*, 1986; Simon *et al.*, 1986; Winkelmann, 1986).

The significant decrease in the number of amputations on diabetics is thoroughly discussed by Ebskov (1991). Probably the main reasons for the decrease are:

1. improved diabetic (blood-glucose) control and self-care programmes;
2. an increasing number of specially trained podiatrists;
3. vascular surgery;
4. improved life-style (smoking-habits, food, exercise etc.).

Contrary to the diabetic amputations the only possible reason for the decrease in the number of vascular insufficiency amputations seems to be an increase in the vascular surgery in Denmark, an issue presently under study.

During the last decades strong efforts have been directed to decreasing the number of AK amputations for vascular insufficiency with or without diabetes mellitus. Comparison of earlier and present studies clearly shows the impact of these efforts. Most important seems to be an increase in the availability of sophisticated equipment for predicting wound healing in lower limb amputations (Holstein, 1985; Ameli *et al.*, 1989; Burgess, 1983; Dwars *et al.*, 1989; Gebuhr *et al.*, 1989; Malone *et al.*, 1987; McCollum *et al.*, 1988; Oishi *et al.*, 1988; Wagner *et al.*, 1988). The role of increasing vascular surgery in Denmark, in relation to the observed changes in level distribution is uncertain, but may have some importance.

BK and foot amputation are more frequent than the AK amputations in diabetic patients, compared to patients with non-diabetic vascular insufficiency (Ecker and Jacobs, 1970; Hansson, 1964; Pohjolainen and Alaranta, 1988). The difference in the distribution of level between the quantitatively dominating amputation groups, i.e. non-diabetic vascular insufficiency and diabetic patients, is probably a consequence of the difference between the distribution of the vascular disease i.e. the involvement of smaller and more peripheral vessels in the diabetic limbs (Falkel, 1983). The present study (Fig. 3) emphasizes this by showing a considerable decrease in the relative size of the diabetic group as the level becomes more proximal, which stresses the importance

of differentiating between non-diabetic vascular insufficiency and diabetic amputation.

Hemipelvectomy and disarticulation of the hip are relatively rare amputations (about 1% of all). The hemipelvectomy group is dominated by malignant skeletal and soft tissue tumour amputations (54%).

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Function after through-knee compared with below-knee and above-knee amputation

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Abstract

Fifty-nine amuptees, 24 below-knee (BK), 17 through-knee (TK) and 18 above-knee (AK) who had prosthetic replacements, were evaluated using a questionnaire which provided a quantitative and qualitative assessment scale for the prosthetic function.

The ability to apply or don the prosthesis was noted in 100% of the BK, 70% of the TK and 56% of the AK amputations ($p<0.001$). Daily use of the prosthesis was recorded in 96% of the BK, 76% of the TK and 50% of the AK amputations ($p<0.001$). A higher level of amputation resulted in a significantly lower degree of rehabilitation ($p<0.05$).

The qualitative evaluation shows that the higher the level of amputation, the lower the usefulness of the prosthesis. Four percent of the BK, 12% of the TK and 39% of the AK amputees had no use whatsoever of their prosthesis ($p<0.01$).

From a functional standpoint, TK amputation should always be considered as the primary alternative to AK amputation when a BK amputation is not feasible.

Introduction

Good surgical results after through-knee (TK) amputation have been reported since the 1950's (Batch *et al.*, 1954; Early 1968). The operative technique is described in more recent publications by Baumgartner (1979), Jansen and Jensen (1983), Jensen *et al.* (1982), Burgess (1977) and Stirneman *et al.* (1987). Despite good results, this amputation level is still frequently neglected. One reason is that it is inevitable that the knee construction makes the femoral part of the prosthesis comparatively longer and the lower part consequently somewhat shorter compared with the normal leg (Jensen *et al.*, 1982; Mensch, 1983). When the patient is sitting, the prosthetic knee joint protrudes compared with the normal side (Fig. 1). Another important point is that the number of wound-healing complications after a TK amputation is higher than after an above-knee (AK) amputation, with delayed healing or re-amputation as the result. The reported frequency of re-amputation after TK amputation varies between 10 to 27% (Stirneman *et al.*, 1987; Jensen *et al.*, 1982; Baumgartner, 1979). There are, on the other hand, several studies reporting the advantages of TK amputation as compared to AK amputation (Stirneman *et al.*, 1987; Baumgartner, 1979; Jensen *et al.*, 1982; Burgess, 1977). Studies by Stirneman *et al.* (1987) and Houghton *et al.* (1990) emphasise

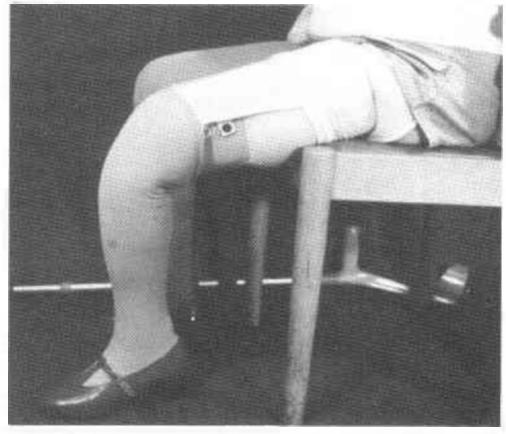

Fig. 1. In a sitting position. the prosthetic knee joint protrudes more on the side of the TK amputation compared with the normal side.

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that TK amputation should be performed when the clinical indications of wound-healing for the below-knee (BK) level are severely reduced.

At the Orthopaedic Workshop and Rehabilitation Centre for leg amputees in Gothenburg, Sweden, the number of TK amputees steadily increased between the years 1985 and 1987. This study was initiated to evaluate the rehabilitation of these patients compared with patients amputated below or above the knee. The purpose of this study is to evaluate the functional ability and the emotional acceptance of the prosthesis among patients subjected to TK amputation compared with BK and AK amputees.

Patient selection criteria

All the patients who underwent a TK amputation and were fitted with prosthetic replacements at the Gothenburg Orthopaedic Workshop and still were alive on December 31, 1987 constituted the basis of the patient selection. To obtain a homogeneous population, patients younger than 50 years and those who had been amputated more than 5 years ago were excluded, as were patients who underwent bilateral amputation. Patients suffering from another severe disease or handicap to the extent of being bed-ridden or totally limited to wheelchairs were also excluded. Finally, blind patients and patients with severe visual disturbances were also excluded, as were patients who could not communicate in Swedish.

Nineteen patients who underwent TK amputation fulfilled all the criteria. All the patients who underwent AK or BK amputation, who had visited the Orthopaedic Workshop between 1986-1987 and who fulfilled the above criteria were included in the control groups. This resulted in a total of 25 AK amputees. From the larger group of BK amputees who satisfied the same criteria, 25 were randomly selected to participate in this study. The total number of patients in the study was therefore 69.

Material

Ten patients were excluded for reasons which became apparent during the study; 1 BK (did not wish to participate), 2TK (1 deceased, 1 developed severe disease), and 7 AK (2 deceased, 2 developed severe diseases, 1 became a bilateral amputee, 1 gave up the prosthesis after a short time, 1 did not wish to participate). Of the remaining 59 patients, 24 were BK (12 men/12 women) with a mean age of 74 years (53-87), 17 TK (9 men/8 women) with a mean age of 74 years (53-82), and 18 AK (12 men/6 women) with a mean age of 71 years (54-85).

Vascular insufficiency (including arteriosclerosis and diabetes) was the most common cause of amputation in all groups; BK 88%, TK 82% and AK 83%. The patients were fitted with the prosthesis the rehabilitation team regarded as being most suitable. Of the 24 BK amputees, 17 (71%) had a PTB (Patellar Tendon Bearing) prosthesis, 5 (21%) had a KBM (Kondylen Bettung Münster) prosthesis, and 2 (8%) had a PTS (Prothese Tibiale Supracondylienne) prosthesis. Of the 17 TK amputees, 15 (88%) had a Gothenburg model of the TK prosthesis (Fig. 2). This prosthesis has an open cuff with a medial frame, a dynamic lateral condylar anchorage and a polycentric knee joint. Two patients (12%) had a conventional TK prosthesis with a leather cuff and a hinge joint. Of the 18 AK amputees, 13 (72%) had a suction socket prosthesis and 5 (28%) had a detachable cuff used for elderly patients.

Methods

All the patients were interviewed in person by the same author (KH). Before the interview, the patients were informed about the study and asked for their voluntary, anonymous participation. At the time of the interview, the amputee had used the prosthesis for a minimum

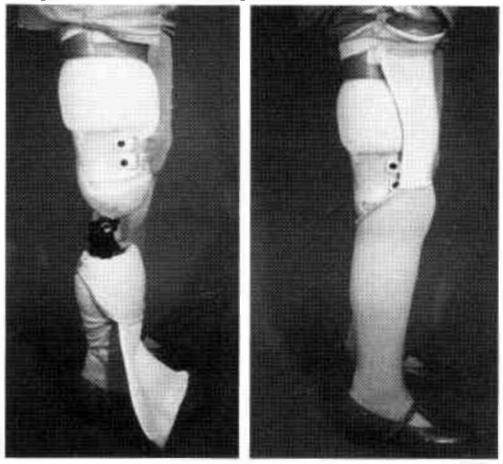

Fig. 2. Prosthetic replacement after through-knee amputation.

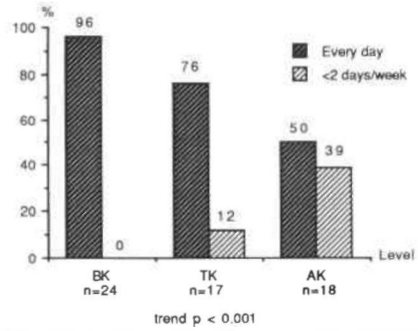

Fig. 3. Distribution (percent) of amputees who use the prosthesis every day and less than two days per week respectively in relation to the level of amputation.

of 6 months. A questionnaire, which was partly inspired by Day's protocol for the examination of amputee activities, was constructed for the interview (Day, 1981). The questionnaire is subdivided into three sections. The first section contains personal data, the second section describes the prosthetic rehabilitation, and the last section evaluates the patient's subjective assessment of the prosthetic replacement. In the last section the answers are graded on a scale of 1-7.

The results have been computerised and the following statistical methods have been used; mean and median values, Chi-square test with Yate's correction and Chi-square trend for proportions by Armitage (Armitage, 1974).

Results

At the time of the interview, the TK amputees had had their prosthetic replacements on average for a shorter period of time than the other two groups; TK 17 months versus BK 26 months and AK 39 months.

Seventeen percent of the BK amputees reported a fear of their prosthesis loosening, the corresponding figures for TK and AK were

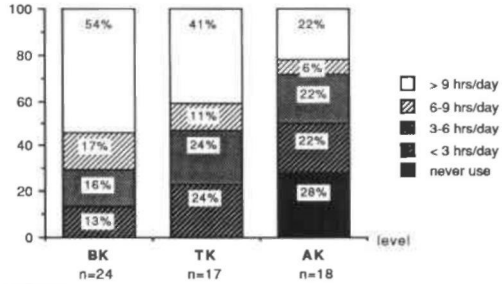

Fig. 4. Distribution (percent) of numbers of hours per day the amputee uses the prosthesis in relation to the level of amputation.

18% and 41% respectively. In order to retain the prosthesis, a suspension with a band around the waist was necessary in 4% of BK, 6% of TK, and 44% of AK ($p<0.05$). Thirty-three percent of BK, 6% of TK and 17% of AK reported that they sometimes or always had to bandage the stump in order to be able to apply the prosthesis. Fifty percent of the BK amputees reported that they sometimes or always had pain using the prosthesis, compared with 35% for the TK and 68% for the AK.

The quantitative use of the prosthesis per week is described in Figure 3. Daily prosthesis use declined with rising levels of amputation ($p<0.001$). Five of the AK amputees (28%) did not use their prosthesis at all. All these patients had used their prosthesis for a minium of 6 months, but had abandoned their rehabilitation after that. Figure 4 describes the number of hours per day the patients used their prostheses. Thirty-three percent of the BK amputees reported that they often or always used a wheelchair indoors compared with 63% of the TK amputees and 56% of the AK amputees (n.s.). When it came to walking aids, 67% of the BK, 18% of the TK and 28% of the AK were able to care for themselves without these aids or only needed one crutch/cane while walking indoors. The difference between BK and TK is statistically significant ($p.<0.05$). Two crutches or a walker were used by 33% of the BK, 82% of the TK and 44% of the AK amputees. Approximately 80% of the patients, independent of amputation level, were able to return to their homes. The rest of the patients lived in apartments for the elderly or disabled.

The functional evaluation of the three different groups of amputees is presented in Figure 5. This section of the questionnaire was answered with a "yes" or "no". It was statistically significant (Chi-square trend for proportions by Armitage) that the higher the level of the amputation, the lower the proportion of patients who were able to apply the prosthesis alone ($p<0.001$) and the lower the number of patients who were able to travel in an ordinary car ($p<0.05$).

The cumulative degree of rehabilitation was rated using a system where five different functions were weighted differently (Fig. 5); prosthetic application 10 points, walking outdoors 7 points, walking up/down stairs 5 points, travelling by car 5 points, managing

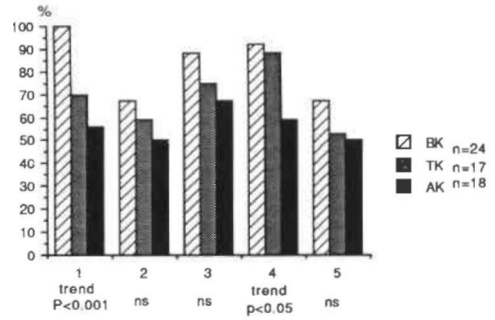

Fig. 5. Grade of rehabilitation among prosthesis users in relation to the level of amputation. The bars describe the distribution (percent) of patients with the described functional ability.
The number (1–5) relates to the ability to perform the following functions with the prosthesis:
1. apply the prosthesis
2. walk outdoors
3. walk up and down stairs with support of the handrail and a crutch
4. travel in a car
5. perform easy household chores (washing up, light cleaning, watering plants)

simple housework 7 points. The results were analysed using a computer and the trend showed that the higher the level of amputation, the lower the degree of rehabilitation ($p<0.05$). The female patients performed on average more poorly than the male patients.

The results of the qualitative evaluation are described in Figure 6. The higher the level of amputation, the higher the proportion of patients with moderate to severe difficulty applying the prosthesis ($p<0.001$). In a similar way, the patients with a higher level of amputation had more problems visiting the lavatory compared with amputees with lower levels of amputation ($p<0.001$).

Four percent of the BK amputees reported that they had no use of the prosthesis whatsoever, the corresponding figures for TK and AK amputees were 12 and 39% respectively. The trend for the prosthesis not to influence the amputee's activities of daily living was higher the lower the level of the amputation ($p<0.01$).

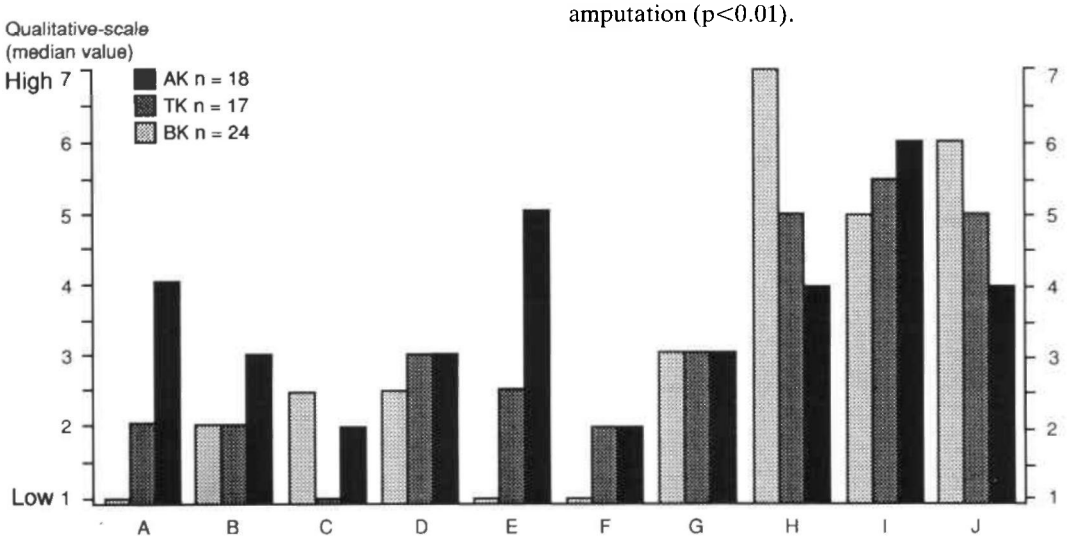

Fig. 6. Qualitative functional evaluation of the three different levels of amputation expressed as the median value on a rating scale of 1-7.
Qualitative rating among prosthesis users regarding:
A. difficulty for the patient to apply the prosthesis
B. how strenuous it is to walk 25 metres indoors
C. pain when using the prosthesis
D. awareness of the weight of the prosthesis
E. difficulty in sitting on the lavatory*
F. discomfort of sitting in an ordinary chair**
G. getting out of an ordinary chair**
H. value in activities of daily living
I. prosthetic design***
J. overall prosthetic function

* 2/24BK, 1/17TK, and 5/18 AK never used the prosthesis while visiting the lavatory.
** 1/24 BK, 4/17 TK, and 3/18 AK never sat in ordinary chairs with the prosthesis.
*** 1/17 TK could not answer the question.

Discussion

The advantages of BK amputation compared with AK amputation have previously been reported (Kegel *et al.*, 1978). The energy consumed by walking with the prosthesis is less and the walking velocity higher (Walters *et al.*, 1976). The TK amputee with a prosthetic replacement has also been reported to have several advantages as compared to the AK amputee. Since the distal femur is left intact, the stump tolerates weight-bearing more effectively (Liedberg, 1982; Hughes, 1983). The shape of the stump permits the simplified suspension of the prosthesis, which is consequently easier to apply compared with an AK prosthesis. Since most of the muscle compartments around the hip joint and the distal end of the femur are intact, there is no muscle imbalance, thereby resulting in a decreased risk of reduced motion of the hip joint. Futhermore, the long lever arm results in a good prosthetic gait with better balance and control of the prosthesis (Stirnemann *et al.*, 1987; Baumgartner, 1979; Jensen *et al.*, 1982; Burgess 1977). The development of various new types of polycentric knee construction (Öberg, 1983) and new types of prosthetic cuff have also improved prosthetic replacements after TK amputations. Stirnemann *et al.* (1987) reported that 84% of the BK, 66% of the TK, and 22% of the AK amputees in their study were "fully rehabilitated and regained their physical and psychic independance". In a Danish study, Jensen and Mandrup-Poulsen (1983) report that 72% of the BK, 69% of the TK and 41% of the AK amputees who had been discharged from the hospital "achieved an outdoor walking capacity". These findings agree well with the present study.

Fewer of the TK amputees than the AK amputees were afraid of being unable to retain their prostheses in the present study, and a significantly smaller proportion of the patients needed a waistband on the prosthesis. The TK prosthesis attachment with the dynamic anchorage above the femoral condyle resulted in a safe suspension. Furthermore, only 1 of 17 TK amputees needed to bandage the stump before applying the prosthesis. Experience shows that bandaging the stump after the TK amputation is often unnecessary. Likewise AK amputees with prosthetic replacements with an adjustable socket did not need to bandage the stump. It is interesting to note that the TK amputees reported less pain when using the prosthesis compared with AK amputees and BK amputees. This may be explained by the surgical technique of not using osteotomy at TK amputation and the favourable prosthetic suspension permitted by the femoral condyles.

Although no patient in this study was amputated more than 5 years ago, the TK amputees had not had their prostheses as long as the other two groups. This could possibly explain why as many as 82% of the TK amputees were using two crutches or a walker. Since the interview, some of the patients at the Rehabilitation Centre have improved their gait ability and, in some instances, have stopped using walking support after continued rehabilitation. The amount of wheelchair use has also been reduced in some cases. In the qualitative assessment, some patients reported that they had never tried to use the prosthesis when visiting the lavatory or sitting in ordinary chairs. Most of these BK and TK patients had not had their prostheses for more than 6 months. Of the AK amputees, all the patients with the corresponding disability had had their prosthetic replacements for more than 12 months (Fig. 6).

When it comes to the inability to apply the prosthesis, it is known from experience that the TK amputees need only a slight amount of help, something a relative of the same age as the patient can usually cope with. For the AK amputee with a suction socket prosthesis, professional help is usually required. Since more than 75% of the patients still live in their own homes, the ability to climb stairs and travel by ordinary car plays an important part in personal freedom. This study shows that the higher the level of the amputation, the less the tendency to master these abilities. Patients with unsuitable flats who do not master these functions are largely imprisoned in their homes.

It has been thought that TK patients have a low prosthesis acceptance for cosmetic reasons (Fyfe, 1990). In this study, there was no difference in the level of cosmetic acceptance between the different groups. One reason could be that the better the grade of rehabilitation and activity level of the patient, the greater the demands imposed on the cosmetic appearance of the prosthetic device. When analysing which subgroups reported dissatisfaction with the

appearance of the prosthesis it was found that women with BK amputation were most dissatisfied (58% low acceptance). One probable reason for this is the difficulty of achieving a sufficiently slim prosthetic ankle.

While the results of this study suggest functional advantages for the TK compared with the AK amputation, the size of the study population limits some of these observations to statistical trends rather than statistically-significant differences. One of the major difficulties in obtaining a sufficient patient population is the high death rate and the occurrence of concurrent diseases which frequently afflict patients undergoing lower limb amputations (Kihn *et al.*, 1972).

TK and AK amputations are sometimes considered to be equivalent procedures since both required prostheses with mechanical knee joints (Fyfe, 1990; Beekman and Axtell 1987). This study, however, shows that there are significant differences in function for patients with TK and AK amputations:
the TK amputee uses the prosthesis more frequently than the AK amputee;
the TK amputee has a higher degree of rehabilitation than the AK amputee;
the TK amputee has more daily use of the prostheses compared with the AK amputee.

Thus, from a functional standpoint, TK amputation should always be considered as the preferred alternative to AK amputation when a BK amputation is not feasible (Stirnemann *et al.*, 1987; Houghton *et al.*, 1990).

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Functional evaluation by gait analysis of various ankle-foot assemblies used by below-knee amputees

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Abstract

Twelve different prosthetic feet were tested by 10 male subjects with right below-knee amputations. Level walking with each prosthetic foot was investigated using a pair of force plates.

Five parameters were selected to compare the functional characteristics of the feet: 1) step length, 2) walking velocity on the sound side in relation to the prosthetic side, 3) depth of valley in the pattern of the vertical component of the floor reaction force, 4) efficiency of the deceleration and acceleration by the prosthetic foot, and 5) irregular patterns in the wave form of the fore and aft components of the floor reaction force. Each of the above parameters was rated numerically. The total score of the objective evaluation attained by analysing the five parameters showed some coincidence to the results of subjective evaluation.

However, a good correlation existed between the objective negative score and the subjective negative rating ($p<0.05$). Non-axial feet developed recently, such as the SAFE II and Seattle Light feet achieved higher scores in the older age group, while single-axis feet, such as the LAPOC and Otto Bock feet achieved higher scores in the younger age group ($p<0.05$).

Introduction

Many ankle-foot assemblies have been developed recently and are now available. However, none of them is equipped with a mechanism that allows an in-use adjustment by the prosthetist or patient in order to respond to the individual needs of the amputee (Aoyama, 1987). Many physicians who prescribe prostheses are hampered by the lack of objective, functional data that would allow selection of the most suitable foot for a specific amputee. To facilitate the task of prescription the functional features of various prosthetic feet were investigated in this study.

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Subjects and methods

Twelve different prosthetic feet were selected. There were three single-axis (domestic, Otto Bock, LAPOC), two multi-axes (Greissinger, Multiflex) and seven non-axial feet (Otto Bock Dynamic, domestic SACH, SAFE II, Carbon Copy II, Quantum, Seattle, Seattle Light). These were fitted on ten male subjects (mean age: 51.1 years) with right below-knee amputations. Five of the subjects were under the age of 50 (30 to 49 years; mean age: 39.4 years), while the rest were aged over 50 (53 to 71 years; mean age: 62.8 years) (Table 1). During level walking at the velocities at which the subjects could walk comfortably the ground to foot force components were measured for each prosthetic foot using a pair of force plates. The walking velocities were determined by dividing the stride length by the swing phase period. The walking velocities were distributed between 1.07 and 1.23 m/s. A force plate with a sampling rate of 50 Hz was used to measure the three components of the floor reaction force of the left and right foot

Table 1. Clinical profiles of the 10 male subjects with below-knee amputations.

	subject	age (yrs)	height (cm)	weight (kg)	stump length (cm)	stump length /height (%)	foot in normal use	socket	duration after amputation (yrs)	activity (score)
over 50 years	T.S.	71	180	47.6	27.0	15.0	LAPOC single-axis foot	PTB	48	31
	M.S.	66	161	54.9	13.5	8.4	LAPOC single-axis foot	KBM	21	20
	T.I.	53	165	58.0	14.0	8.5	DYNAMIC foot	PTB	2	33
	K.K.	61	157	55.0	26.0	16.6	LAPOC single-axis foot	PTB	4	30
	M.U.	63	160	56.0	13.0	8.1	LAPOC single-axis foot	PTB	7	23
under 50 years	T.H.	49	165	61.5	12.0	7.3	LAPOC single-axis foot	PTB	28	36
	S.H.	38	173	64.3	22.0	12.7	LAPOC single-axis foot	PTB	19	46
	H.H.	30	165	61.0	19.0	11.5	QUANTUM foot	PTB	10	37
	S.K.	40	165	65.0	11.5	7.0	OTTO BOCK single-axis foot	PTB	14	39
	K.Y.	40	168	45.8	13.5	7.7	LAPOC single-axis foot	PTB	30	26
mean values		51.1	165.9	56.9	17.2	10.3			18.3	32.1

during the support phase. The floor reaction force was normalised according to the weight and period of double support for each subject. In addition, level walking was analysed in five healthy males (control subjects) aged from 28 to 54 years (mean age: 40.8 years).

Five parameters and two types of evaluation were identified as effective in comparing the walking of normal subjects and amputees using prostheses. The parameters used to characterise the performance of the ankle-foot assemblies were as follows:

1. Step length ratio: The ratio of the step length of the left leg (sound side) to the step length of the right leg (prosthetic side).
2. Walking velocity ratio: The ratio of the walking velocity of the right lower leg (prosthetic side) to the walking velocity of the left lower leg (sound side). The walking velocities of both lower feet were measured separately and determined by dividing the stride length by the swing phase period.
3. Depth of the valley: The depth of the valley in the pattern of the vertical component of the floor reaction force (the level of minus velocity at mid-stance) was determined as an indicator of the smoothness of walking. The difference between the mean value of the first peak (P1) and second peak (P2) and the valley (V): (P1+P2)/2-V.
4. Efficiency of deceleration and acceleration: The efficiency of deceleration and acceleration was determined by adding the absolute values of the maximum deceleration force (Dmax) and the maximum acceleration force (Amax) according to the fore and aft component of the floor reaction force: Dmax+Amax.

The mean values and standard deviation (SD) of the above four parameters were

Table 2. Questionnaire for subjective evaluation.

1. Do you feel the hardness of the heel is appropriate or not?
too hard, appropriate, too soft.

2. Is it possible to roll-over on your prosthetic foot smoothly or not?
smooth, not smooth (feels like climbing over hill)

3. At push-off, is the knee of your amputated side stable enough or not?
stable enough, unstable (premature knee flexion)

4. Do you feel the weight of prosthetic foot is too heavy or not?
too heavy, reasonable, light enough

5. Does the prosthetic foot match to your walking style or not?
yes, no

Subjective evaluation of each prosthetic foot was classified into the following three groups according to the answers for above questionnaire as;
A: good, B: acceptable, C: unacceptable

determined for each individual subject. A score of +10 points was assigned when a value of an ankle-foot assembly was equal to or greater than +SD, a score of 0 points was assigned when the value was within ± SD, and a score of −10 points was assigned when the value was equal to or less than − SD.

5. An irregular pattern in the wave of the fore and aft component of the floor reaction force on the prosthetic side: There are cases in which at the beginning of the heel contact or push-off stage an irregular wave pattern occurs in the fore and aft component of the floor reaction force on the prosthetic side. As this is evidence that

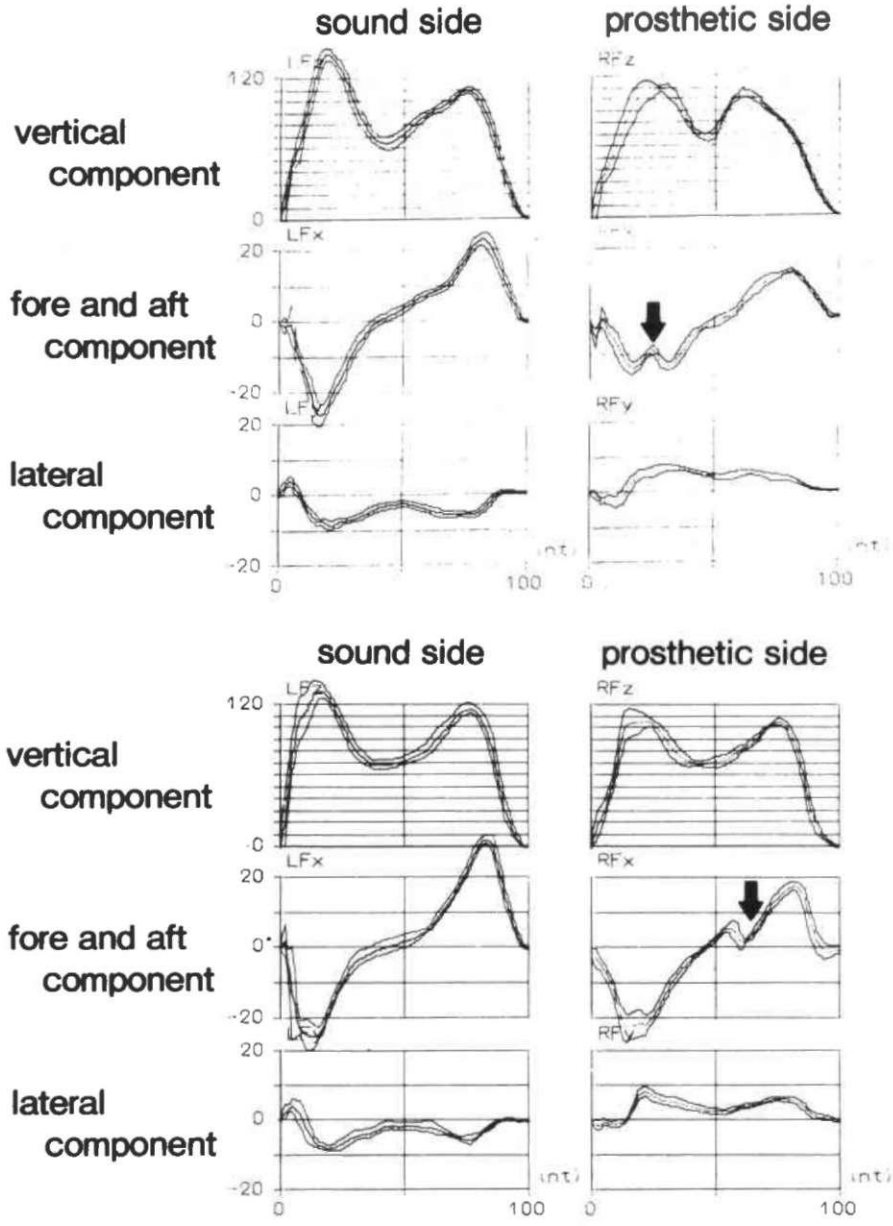

Fig. 1. Irregular wave patterns of the fore and aft component of the floor reaction force. Arrows indicate the irregular wave patterns at the beginning of the heel contact or push-off stage.

roll-over of the lower foot was not occurring smoothly, 10 points were subtracted when such a pattern was observed (Fig. 1).

6. Subjective Evaluation: In order to provide a comparison with the objective evaluation, a subjective evaluation of the ankle-foot assemblies was obtained from the subjects using a simple questionnaire. Subjective evaluation of each prosthetic foot was classified into the following three groups according to the answer to the above questionnaire as; A: good, B: acceptable, and C: unacceptable (Table 2).
7. Activity Evaluation: The activity level of each amputee was scored using the activity evaluation chart prepared by Day (1981).

The t-test, chi-squared test, correlation coefficients, and linear regression were used for statistical analysis. The level of significance was set at $p<0.05$.

Results

Measured parameters

Some ankle-foot assemblies could not be evaluated on some amputees because the stump was too long to allow attachment.

1. Step length ratio: The ratio of the left step length to the right step length was 96.1 ± 1.36(%) in the control group and 85.9 ± 6.29(%) in the amputee group (Table 3). The step length on the prosthetic side was significantly longer than the sound side ($p<0.01$). In addition, this ratio was observed to vary for different ankle-foot assemblies. For example, the ratio values of the domestic single-axis foot and foot normally used were large, while those of the Carbon Copy II and Greissinger feet were small.

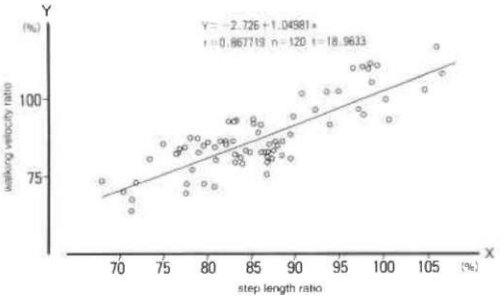

Fig. 2. The relationship between the two variables satisfies a linear regression of $Y=-2.726+1.04981\ X$, $(n=120)$.

2. Walking velocity ratio: The ratio of the walking velocity of the right lower leg to the walking velocity of the left lower leg was 94.3 ± 2.70(%) in the control group and 87.3 ± 8.12(%) in the amputee group (Table 3). Although no significant difference was observed between the two groups of subjects, the walking velocity ratios differed among the various ankle-foot assemblies. For example, the ratio values of the SAFE II and domestic single-axis feet were large, while those of the Greissinger and Quantum feet were small (Table 4).

The correlation between the step length ratio and the walking velocity ratio was quite strong ($r=0.867719$) (Fig. 2).

3. Depth of the valley: A value of 28.87 ± 12.398 (BW%) was determined for the prosthetic side of the amputee group in contrast to a value of 46.23 ± 4.60

Table 3. Comparison of normal limbs and prostheses during walking in 10 men with below-knee amputations.

group classification / parameter		step length ratio (%)	walking velocity ratio (%)	depth of valley (BW%)	efficiency of deceleration and acceleration (BW%)	frequency of irregular wave patterns (%)
control group		96.1±1.36	94.3±2.70	46.23±4.60	45.85±3.93	0.0
prosthetic side		85.9±6.29 *	87.3±8.12	28.87±12.39 *	29.31±5.56 *	21.7
Age	over 50 yrs	87.8±2.94	88.5±2.79	29.25±8.96	26.99±3.35	23.7
	under 50 yrs	84.0±7.95	86.1±11.00	28.48±15.05	31.62±6.62	19.7
Stump length /height	large	84.2±5.13	86.4±4.16	38.17±8.86	31.74±6.26	12.3
	small	87.7±6.83	88.2±10.63	19.56±7.46 **	26.87±3.31	30.2 **
Time since amputation	long	87.9±7.66	90.4±9.73	25.11±9.21	30.70±6.53	12.3
	short	84.0±3.57	84.2±4.20	32.62±13.93	27.91±3.92	30.2 **

*P < 0.01 **P < 0.05

Table 4. Comparison of the 12 ankle-foot assemblies.

parameter / prosthetic foot	step length ratio	walking velocity ratio	depth of valley	efficiency of dec. and acc.
foot normally used	88.4	89.1	28.76	28.75
DYNAMIC foot	86.3	87.2	28.45	29.23
domestic SACH foot	88.0	88.6	33.36	27.44
SAFE II foot	87.7	91.0	25.51	26.36
CARBON COPY II foot	83.9	86.8	24.14	25.91
QUANTUM foot	84.2	85.8	28.97	30.98
SEATTLE foot	85.4	86.5	27.71	29.32
SEATTLE LIGHT foot	85.5	86.4	28.80	27.38
domestic single-axis foot	90.2	90.0	24.98	28.76
OTTO BOCK single-axis foot	86.3	86.6	30.80	32.81
LAPOC single-axis foot	86.1	86.4	30.90	31.12
GREISSINGER foot	82.3	85.9	26.40	29.27
MULTIFLEX foot	85.3	88.7	27.65	31.55
mean values	85.9	87.3	28.87	29.31

dec.: deceleration, acc.: acceleration

(BW%) for the control group (Table 3). The depth of the valley was significantly reduced on the prosthetic side ($p<0.01$). A value of 46.45 ± 10.40 (BW%) for the sound side of the amputee group was almost equal to the value of the control group. Values for the individual types of ankle-foot assembly varied; the values of the domestic SACH and LAPOC single-axis feet were large, but those of the domestic single-axis and Carbon Copy II feet were small (Table 4).

4. **Efficiency of deceleration and acceleration:** A value of 29.31 ± 5.56 (BW%) was determined for the prosthetic side of the amputee group in contrast to a value of 45.85 ± 3.93 (BW%) for the control group (Table 3). The efficiency of deceleration and acceleration was significantly inferior on the prosthetic side ($p<0.01$). A value of 46.29 ± 6.66 (BW%) for the sound side of the amputee group was almost equal to the value of the control group. Values for individual types of ankle-foot assembly varied; the values of the Otto Bock single-axis and Multiflex feet were large, but those of the SAFE II and Carbon Copy II feet were small (Table 4).

The correlation between the depth of the valley and the efficiency of deceleration and acceleration was moderate ($r=0.53486$) (Fig. 3).

The subjects were divided into three classes each containing two groups of five subjects each according to: 1) those over 50 years old (53 to 71 years; mean age: 62.8 years) those under 50 years old (30 to 49 years; mean age: 39.4 years); and 2) those whose ratio of residual limb length to

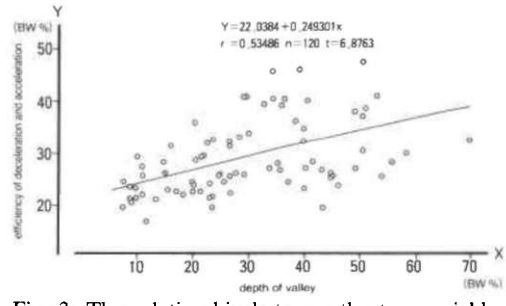

Fig. 3. The relationship between the two variables satisfies a linear regression of $Y=-22.0384+0.249301X$, ($n=120$).

height (abbreviated as stump length/height) was large (8.5 to 16.6%; mean: 12.9%) versus those whose stump length/height ratio was small (7.0 to 8.4%; mean: 7.7%), and 3) those whose time since amputation was long (19 to 48 years; mean: 29.2 years) versus those whose time since amputation was short (2 to 14 years; mean: 7.4 years). When examined in this manner, although the values for the depth of the valley were larger in the group with the larger stump length/height ratio ($p<0.05$), no differences were observed with respect to the other parameters (Table 3).

5. An irregular pattern in the wave of the fore and aft component of the floor reaction force on the prosthetic side.

No cases had irregular wave patterns on the sound side. But the frequency of irregular wave pattern on the prosthetic side was highest in the domestic SACH foot and the Seattle foot. There were no irregular wave patterns in the Otto Bock single-axis foot (Table 5). In addition, when the frequency of irregular wave pattern was examined by dividing the subjects into the three sub-groups described above, although no difference was observed between the group over 50 years old and the group under 50 years old, the irregularity was decreased in proportion to stump length or time since amputation. Those with longer stump or greater time since amputation demonstrated smaller wave disturbances ($p<0.05$) (Table 3).

6. Subjective evaluation: The distinction between "good" and "acceptable" was not always clear and appeared to be influenced by the intelligence, comprehension, and level of interest of the subjects. Some replies were vague, for example, "not bad" and "fairly good". With respect to "unacceptable" ratings, however, those ankle-foot assemblies that did not function well were identified with relative ease, and were described in such terms as "difficult to walk with".

7. Activity evaluation: The activity score rating of the subjects varied between +46 to +20 (mean: +32.1). Their activities were all classified as "very high" or "high" according to the rating of Day (1981). No significant correlation was observed

Table 5. Irregular wave patterns of the fore and aft component of the floor reaction force on the prosthetic side.

prosthetic foot \ subject	T.S.	M.S.	T.I.	K.K.	M.U.	T.H.	S.H.	H.H.	S.K.	K.Y.
foot normally used	○	○	○	○	○	○	○	○	○	×
DYNAMIC foot	○	○	○	○	×	○	×	×	○	○
domestic SACH foot	×	×	×	○	×	○	○	○	○	○
SAFE II foot	○	○	○	○	○	○	○	○	○	×
CARBON COPY II foot	○	×	×	○	×	○	○	○	○	○
QUANTUM foot	○	○	○	/	×	○	○	○	○	○
SEATTLE foot	○	○	○	/	×	×	○	○	×	×
SEATTLE LIGHT foot	○	○	○	○	×	○	/	○	○	×
domestic single-axis foot	○	○	○	/	×	○	×	/	/	×
OTTO BOCK single-axis foot	○	○	○	○	○	○	○	○	○	○
LAPOC single-axis foot	○	○	×	○	○	×	○	○	○	○
GREISSINGER foot	○	○	○	/	×	○	○	○	○	○
MULTIFLEX foot	○	○	○	/	/	○	/	○	×	○

×: irregular wave patterns were observed. ○: irregular wave patterns were not observed.

between the stump length/height and activity level ($p<0.05$). In addition, because the elderly subjects also demonstrated high levels of activity, no significant correlation was observed between age and activity level (Table 1).

Scoring of the objective evaluation

1. Comparison of the objective and subjective evaluations: The objective and subjective evaluations were not always in agreement. However, in the 13 cases where the subjective evaluation was "unacceptable", 6 also yielded negative scores in the objective evaluation, and only 2 had positive scores. In contrast, among 66 cases where the subjective evaluation was "good", only 11 had a negative score in the objective evaluation. Thus, a subjective evaluation of "unacceptable" was associated more often with a negative score in the objective evaluation than an evaluation of "good" ($p<0.05$). These findings suggest that the objective evaluation standards that were selected identify a negative score with ankle-foot assemblies that do not function properly (Table 6).
2. Suitability of the prosthetic feet: The total scores of the objective evaluations showed that non-axial feet developed recently, such as the SAFE II and Seattle Light feet, received a higher score in the older age group (over 50). Single-axis feet such as the LAPOC and Otto Bock feet, received a higher score in the younger age group (under 50) ($p<0.05$) (Table 7).

Discussion

Many researchers have investigated the temporal and spatial parameters of prosthetic gait with below-knee amputees. Breakey (1976) has reported that the stance phase of the amputated limb occupied 37% of one gait cycle, while the sound side occupied 43%. Robinson *et al.* (1977) have investigated the walking of below-knee amputees using a SACH foot and stated that the step length on the prosthetic side was somewhat longer than that on the sound side. The difference in the mean length was 5 cm at a walking speed of 1.07 m/s. Doane and Holt (1983) have compared the SACH foot to the single-axis foot, and found no difference in walking velocity between the two (both 1.22 m/s).

The results of this study suggest that time-

Table 6. Comparison of objective evaluations and subjective rating.

prosthetic foot \ subject	T.S.	M.S.	T.I.	K.K.	M.U.	T.H.	S.H.	H.H.	S.K.	K.Y.
foot normally used	0A	0A	10A	0A	10A	10A	0A	−10A	0A	−10A
DYNAMIC foot	30A	0A	0A	−10B	−20B	20A	0B	0A	10A	0A
domestic SACH foot	0C	10B	−10B	10A	0A	−10B	−10B	0B	10A	20B
SAFE II foot	0B	0A	20B	20B	0A	−20C	0B	−10C	−10C	0B
CARBON COPY II foot	−20A	−40C	−20A	10A	−40A	−20B	10B	−10B	−20B	−10A
QUANTUM foot	30B	0A	0A	/	−10B	0A	−20B	10A	20A	−10B
SEATTLE foot	0A	0A	0A	/	10A	0C	−20A	0B	−30B	−10B
SEATTLE LIGHT foot	0B	0A	10A	10A	10B	0A	/	0A	−10B	0A
domestic single-axis foot	−30C	20B	−10B	/	0C	0A	10A	/	/	0C
OTTO BOCK single-axis foot	0B	0A	0B	−10A	0A	0A	20A	10B	20B	0A
LAPOC single-axis foot	−30A	0B	−10A	0A	10A	0B	20A	10C	20A	10A
GREISSINGER foot	0B	10A	−10A	/	−30A	0A	0A	−20B	10C	0C
MULTIFLEX foot	20B	20A	0A	/	/	10A	/	30B	−20B	−20C

Table 7. Suitability of the prosthetic feet.

group classification / prosthetic foot	Age		Stump length/height		Time since amputation	
	over 50 yrs. (av. 62.8 yrs.)	under 50 yrs. (av. 39.4 yrs.)	large (av. 12.9%)	small (av. 7.7%)	long (av. 29.2 yrs.)	short (av. 7.4 yrs.)
foot normally used	4±4.9	−2±7.5	0±6.3	2±7.5	0±6.3	2±7.5
DYNAMIC foot	0±16.7	6±8.0	0±13.6	2±13.3	4±13.6	−4±10.2
domestic SACH foot	2±7.5	2±11.7	−2±7.5	6±10.2	−2±7.5	2±7.5
SAFE II foot	8±9.8	−8±7.5	6±12.0	−6±8.0	6±12.0	4±13.6
CARBON COPY II foot	−22±18.0 **	−10±11.0	−6±13.6	−26±12.0	−6±13.6	−16±16.2
QUANTUM foot	5±15.0	0±14.1	5±18.0	0±11.0	5±18.0	5±11.2
SEATTLE foot	2.5±4.3	−12±11.7	−5±8.7	−6±13.6	−5±8.7	−5±15.0
SEATTLE LIGHT foot	6±4.9	−2.5±4.3	−10±16.3	0±6.3	5±5.0	4±8.0
domestic single-axis foot	−5±18.0 **	3.3±4.7	4±10.2	5±8.7	−10±16.3	−5±5.0
OTTO BOCK single-axis foot	−2±4.0	10±8.9	−2±17.2	4±8.0	4±10.2	4±10.2
LAPOC single-axis foot	−6±13.6 **	12±7.5	−2±17.2	8±7.5	−2±17.2	6±10.2
GREISSINGER foot	−7.5±14.8 **	−2±9.8	−7.5±8.3	−2±14.7	−7.5±8.3	−12.5±14.8
MULTIFLEX foot	13.3±9.4	0±21.2	16.7±12.5	−2.5±17.9	16.7±12.5	3.3±20.5

** $p < 0.05$

distance parameters are important for evaluating prosthetic walking. The step length and walking velocity varied with the type of ankle-foot assembly tested as well as the site of amputation. The strong positive correlation between the step length and the walking velocity emphasized the fact that an amputee wearing a prosthetic foot suitable for his activity level can walk faster with longer steps on the sound side, while the opposite also holds true. Thus the speed and step length of the sound limb provide useful guidelines for the selection of an appropriate prosthetic foot.

Assessment of prosthetic feet by the analysis of floor reaction force has also been reported by various researchers. Ehara *et al.* (1985) have compared the degree of irregularity in traces of the fore and aft component of the floor reaction force, and concluded that the main cause of such irregularities was the mechanism of the instep bumper. When dorsiflexion of the prosthetic foot is controlled by smoothly increasing resistance, a smooth transition between the fore and aft shearing forces is also attained.

In this study, the irregular wave pattern was found for the domestic SACH foot in the older age group. In contrast, multi-axes feet such as the Greissinger or Multiflex showed little disturbance of the wave pattern. The irregularity was also rarely seen in the subjects with longer stumps. In this group, the valley in the vertical component force curve was also deeper than in the patients with short stumps. The floor reaction forces are influenced not only by the physical characteristics of the prosthetic foot, but also by the length of the stump, the muscle strength of the lower limb and the duration since amputation. These physiological factors are the most important ones to consider when determining which prosthetic foot is the best choice for a particular patient.

It is well known that as a patient becomes weaker, a softer heel bumper should be chosen. Hardness of the heel bumper can also affect prosthetic walking. This was demonstrated by the gait analysis of an amputee wearing a single-axis foot when heel bumpers of different hardnesses were tested (Kasahara, 1983).

Several sets of clinical guidelines for the selection of prosthetic feet have been reported. Wing and Hittenberger (1989) have suggested that the Flex foot followed by the Carbon Copy II and Seattle feet are suitable for active patients due to their good propelling features. In contrast, those feet such as the SAFE or STEN feet are the choice for less active

amputees. Wirta *et al.* (1991) have identified four variables to use in determining the optimal prosthetic foot (age, actual/ideal body weight ratio, residual limb length/height ratio, and frequency/length of stride ratio).

However, neither of the above mentioned reports has included an objective evaluation of amputee performance with the different prosthetic feet.

In this study, five parameters were selected to use in gait analysis and compared with the objective evaluations to subjective impressions of the amputees. With an optimal prosthetic foot, the amputee can walk faster and achieve an equal step length on both the prosthetic and sound sides. The floor reaction force on the prosthetic side, especially during deceleration and acceleration, will show a regular curve which indicates smooth transition of the centre of gravity.

The assessment of the various prosthetic feet in accordance with the objective evaluation clarified the factors for matching prosthetic feet with the activity level or physical condition of the amputees. It was found that clinical standards used for the selection of a prosthetic foot are fairly compatible with the objective evaluation of amputee performance. Consequently, the older age group (over 50) in the study showed a better performance using the non-axial feet equipped with elastic keel such as SAFE II and Seattle Light feet. On the other hand, the patients age under 50 years performed better with the single-axis feet such as LAPOC or Otto Bock. The results generally coincide with the mechanical features of the prosthetic feet such as weight, hardness of bumpers and toe-break. Both the SAFE II and Seattle Light feet are relatively light and are equipped with an elastic keel which provides firm support and smooth push-off for the older amputees.

Conclusion

1. A significant correlation was confirmed between the step length and velocity of the sound limb ($p<0.05$).
2. Irregularity of the curve describing the fore and aft component of the floor reaction force varied in proportion to the stump length and the duration since amputation. The longer the stump and the duration, the smaller the irregularity of the curve ($p<0.05$).
3. Objective evaluation of five parameters was compared to the subjective evaluation of the amputees. A good correlation existed between the objective score and negative preference by the patients ($p<0.05$).
4. The newly developed non-axial feet (SAFE II and Seattle Light) achieved high objective scores in the patients aged over 50. Single-axis feet of modular systems (LAPOC and Otto Bock) achieved high scores in the subjects under 50 years of age ($p<0.05$).
5. The propelling force at push-off stage and the walking speed increased in proportion to the length of the stump.

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A CAD CAM method for custom below-knee sockets

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Abstract

The purpose of this investigation was to develop a numerical method for fabricating prosthetic sockets for below-knee amputees. An optical/laser digitiser scans an amputee's stump and collects three dimensional numerical data describing the surface of the limb and describing specific modification site locations. The numerical data from the laser camera representing the stump and modification sites are altered by the prosthetist using a custom computer aided design software system running on a personal computer. Using the altered numerical data a programme is created for a high resolution numerically controlled milling machine and a mould is made. The prosthetist then fabricates a socket. While the system has been tested with below-knee amputees it has been designed for application in most areas of prosthetics and orthotics. Utilising this method 15 patients were fitted. All patients sujectively stated that their "computer designed" socket fitted better than their conventionally made socket. As the research progressed and experience was gained with the system patients were normally fitted with the first socket iteration. The system overcomes five limitations existing with some of the other numerical systems:

1) accurate high resolution surface topography, 2) specific identification of subject modification sites, 3) flexible, user friendly software, 4) high resolution numerically controlled milling, and 5) integrated expansion to other prosthetic and orthotic areas.

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Introduction

The most important aspect of a below-knee (BK) prosthesis is the manner in which external loads from the prosthetic socket are transferred to the stump. Unlike a normal limb where external loads from the ground are transferred through tissues of the foot which are intended to bear high loads, the loads for an amputee are transferred from the ground to an artificial foot and leg, to a socket, and finally through tissues on the stump, which were not intended to bear high loads. Despite this it has been established that these tissues can accept load to some degree. However this ability to tolerate load is not homogeneous (New York University Medical Centre, 1980). Therefore the prosthetist must direct the load from the socket to specific areas on the stump that can tolerate load and direct load away from areas that cannot tolerate load. If the loads are directed correctly then the socket is comfortable, the stump is healthy, and the BK amputee is able to engage in activities without pain or discomfort. If the loads are not directed correctly then the socket is uncomfortable, the stump is unhealthy (i.e., chafing, bleeding, bruising, and pressure sores may occur), and the BK amputee is limited in his/her activities.

The current subjectivity associated with the traditional casting and subsequent modification of a positive mould to fabricate a socket prohibits the objective determination of the specific requirements for loading between the socket and the stump. Developing objective quantitative methods for the fabrication of sockets and the numerical evaluation of socket fit will help in the establishment of the basic principles for well fitting comfortable sockets. A first step in this regard and the purpose of

this investigation was to develop a numerical method for fabricating prosthetic sockets for BK amputees.

Review of other numerical systems

Several groups in the world have investigated the numerical quantification of the fabrication of BK sockets. Jim Foort was the first investigator to address the possibility of a quantitative method of socket fabrication. Working with Foort, Saunders *et al.* (1985) used mechanical devices to gather a sample set of measures on a stump. They then selected a positive mould from a small library of computerised positive mould reference images and used the measures to scale and make modifications to the selected image. Finally they utilised numerically controlled (NC) milling to create a modified positive mould. Over time this method of using a library of reference images proved to be unsuccessful and was abandoned.

The Bioengineering Centre (1986) digitised the inside of a negative cast with a mechanical digitiser to obtain a three-dimensional (3D) numerical representation of the stump. They modified this data according to some predetermined criteria, milled out a mould with an NC milling machine and developed a vacuum forming machine for fabricating the socket. Oberg *et al.* (1989) obtained a topographical image of the stump with an optical/laser digitiser and then followed the same general procedure as the Bioengineering Centre (1986) to eventually produce a mould.

Limitations of systems

At least five limitations are present with some or all of these methods. The first is that except for Oberg *et al.* (1989) none of the other investigators has been able to consistently obtain high resolution residual limb topography. The digitising of the inside of a negative cast to obtain an exact duplicate of the stump is only as good as the skill of the prosthetist fabricating the cast. In other words, if that cast is not an accurate representation of the stump neither will be the digitised data of that cast. The resolution of the mechanical digitiser is not high. One hundred and forty-four data points can be obtained from the mechanical digitiser for a 2.54cm band around the stump. Finally, it is difficult or impossible to use the mechanical digitising method to fit all children since the digitiser stylus cannot fit into small casts.

The second limitation is that none of the investigators has developed a system integrated method to individually identify specific regions for modifications. They typically each use one orientation marker and then identify modifications sites from that single marker. The anatomical variation for any given segment of the human body is well documented and it is therefore necessary for these researchers to rely on broad modification site regions or estimate the locations of specific landmarks. In the case of pressure relief modification regions, a larger than necessary modification area reduces the surface area available for higher pressure application. Thus the regions that can accept higher pressures must accept more load than if the pressure relief regions were kept as small as possible.

A third limitation with these systems and one that is gradually being eliminated is the computer software. In general, the software has been based on a two-dimensional (2D) view of the image. While a 3D image may appear on the screen the actual modification is performed on a 2D cross-sectional or profile view. There 2D views may not always provide adequate information from which to make proper modifications to the data and may be difficult to use. In addition, some of the software has not been flexible enough to allow for both standard and individual modifications.

A fourth limitation that exists with some of the systems is that in contrast to the very smooth surface of the positive mould created by the prosthetist, low resolution milling of the positive moulds produces moulds with ridges. These ridges are produced because the cutting tool, at best, can make only eight cutting passes for a 2.54cm band around the mould.

Finally, the fifth limitation is that these methods have been designed for BK and possibly above-knee (AK) amputees. The utilisation of the methods for other applications has not been built into the components.

Methods

A method has been developed for fabricating BK sockets utilising quantitative techniques believed to have overcome the limitations

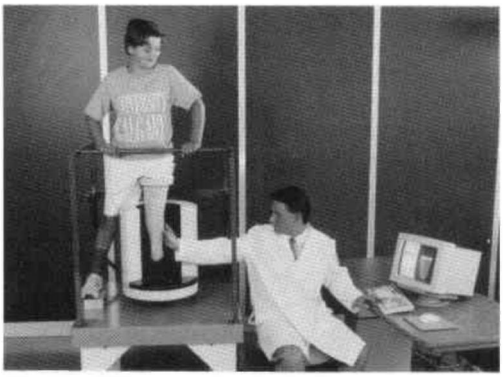

Fig. 1. Digitising parlour including support device, laser camera and computer.

outlined above. To overcome the first two limitations, an optical/laser digitiser (#4012 Cyberware Laboratory Inc.) scans the amputee's stump and collects numerical data describing the surface and describing specific modification site locations (error less than ± 1.5mm) (Fig. 1). A low powered laser projects a line along the length of the stump. The projected line is viewed obliquely by a CCD camera. Then by triangulation, 3D co-ordinates can be obtained from the 40.5 cm laser line. The digitiser assembly rotates 1.4 degrees about the longitudinal axis of the limb, the laser projects another line, and the process is repeated (i.e., 256 lines for 360 degrees) until a topographical mapping of the entire surface of the stump is obtained. The collection of the data by the digitiser is completed in about 10 seconds with 65,536 data points obtained for the full 40.5cm (i.e., 256 lines times 256 points per line). For comparison, 4,110 data points can be obtained from the laser digitiser for a 2.54cm band around the stump. These data are then numerically recorded and stored on a computer. While the scanning only takes about 10 seconds, the entire scanning procedure requires about 20 minutes.

To determine the modification site locations, the prosthetist uses a method similar to that currently employed in the traditional casting method. The prosthetist marks a stockinette placed on the stump of the patient. Marks are made for areas of relief, pressure, alignment, and other relevant modifications as determined by the prosthetist. The laser camera then identifies these marks during the scanning procedure and displays them on the computer screen along with the stump surface topography.

The 3D numerical information from the laser camera representing the stump (or positive mould) and modification sites is altered by the prosthetists using a custom computer aided design (CAD) software system running on a personal computer (PC) (Fig. 2). The CAD system displays any desired view of the positive mould as a 3D wire-frame drawing. The prosthetist further clarifies each modification region that has been specifically identified with the laser scanner using the keyboard and mouse. Each modification region can have any size or shape and the amount of build-up or relief is specified numerically as a displacement. A blending range and shape can also be specified to smoothly merge the modifications with the surrounding surface, thus avoiding abrupt ridges and providing maximum contact with the surface of the stump.

To aid the prosthetist in performing modifications, a standard set of modifications has been developed which can be applied to most BK stumps. The modification set serves as a first best estimate for each modification and reduces the amount of time needed to modify a positive mould. The prosthetist highlights the location of each modification region and the other parameters such as the shape of the region, the displacement, and the blending range are filled in automatically. The prosthetist may then "fine tune" the parameters as required.

The standard modification set represents a consistent numerical procedure for the prosthetist to follow when modifying a positive mould. However, since no two stumps are alike

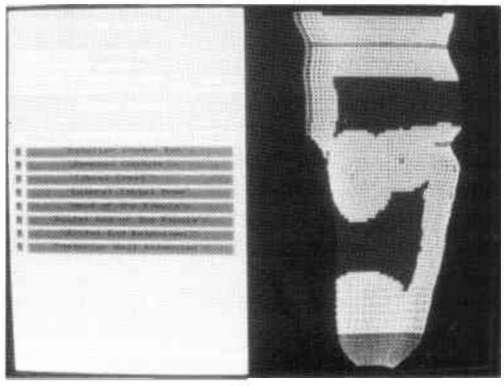

Fig. 2. Image of stump limb after a series of modifications.

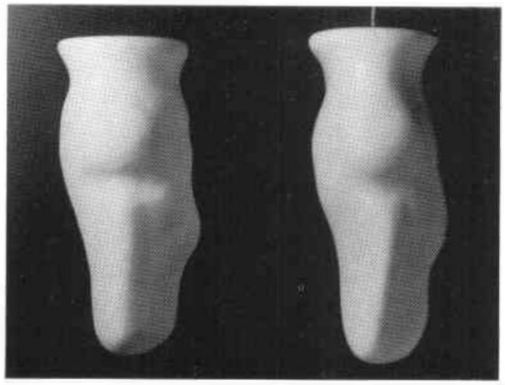

Fig. 3. Positive mould (left) created by the milling machine and positive mould (right) created by the prosthetist for the same patient.

all parameters of each modification can be customised for each individual positive mould. New modifications can be added, unneeded modifications can be omitted and modifications can be blended together. When the prosthetist has completed all modifications to the positive mould the CAD system saves a data file representing the modified positive mould. This process presently takes about 20 minutes to complete.

Using the altered numerical data representing the modified positive mould, a programme is created for an NC milling machine. This high resolution machine mills out a smoothly shaped positive mould by making 256 individual cutting passes down the long axis of the mould (Fig. 3). For comparison with other milling machines 11 to 34 cutting passes can be made for a 2.54cm band around the mould. The number of cutting passes is variable in this comparison since the radius of any transverse section of the mould varies both between and within subjects. In other words, the greater the radius of the cross-section, the greater the distance between cutting passes.

The positive mould information is used as a reference when generating the path for the cutting tool. Complex geometries are considered, taking into account the shape of the cutting tool and the contours of the positive mould to achieve maximal accuracy without gouging. Using a typical industrial milling machine with an old controller and cutting at a higher resolution than other systems, it presently takes about two hours to create the mould. The authors are currently in the process of developing an NC machine that will mill out the BK mould at the current level of resolution in 20 minutes. In addition, the mill will be general enough to mill out moulds in the prosthetic/orthotic applications.

Results and discussion

The purpose of this investigation was to develop a numerical method for fabricating prosthetic sockets for BK amputees. The purpose was not to perform a numerically objective evaluation of the fit and comfort of the sockets that were produced. Investigations designed to evaluate objectively the fit and comfort of sockets are on-going in the laboratory. Hence the evaluation of the functional results of the work in this investigation was entirely subjective in nature.

Utilising this method the writers have fitted 15 patients. As the research progressed and experience was gained it was possible to fit the patients after the first iteration. All the patients have subjectively stated that their "computer designed" socket fits better than their conventionally made socket. This belief may be reasonable since modifications can be applied with the custom software that are virtually impossible utilising conventional methods. For example, it is possible to perform an exact uniform shrink of all or any portion of the stump data set. In contrast, it would be highly unlikely that a prosthetist could file down an entire plaster mould or a large portion of it as precisely, or with as much uniformity. In addition, further confirmation of an adequate fit exists since the 15 patients have been wearing the sockets on a regular, full-time basis without complaint.

This procedure solves the five limitations which the authors suggest currently exist with some of the other CAD CAM systems. The laser scanner records surface topography directly from the stump and does not rely on the inconsistent and potentially inaccurate casting method. The error of the laser scanner is less than $\pm$ 1.5mm and appears accurate enough to meet the needs of the system. The number of data points describing the surface topography of the stump is about 28 times as many using the laser scanner than using a mechanical digitising method (4,110/144). The number of data points needed to provide sufficient description of the stump for developing a positive mould has not been established. However, it is very easy with

this system to reduce the number of data points if that proves adequate, but very difficult for many other systems to increase the number of data points.

The laser camera is also used to identify the specific sites for modification. It does not rely on a library of data or averages from past subjects. It identifies these sites directly thus allowing for more accurate modification.

The root of the CAD software of the other system referred to above is in the original work of Jim Foort. It presently appears that, except for the CAD software developed at the University of Washington (Sidles *et al.*, 1989), the basic ideas existing with Foort's original software is still used by many systems. On the other hand, CAD software described in this paper has been collaboratively designed and developed in recent years by professionals in the fields of prosthetics, orthotics, mechanics, computer geometric modeling, and user interface design. It is very difficult to demonstrate the concept that a computer programme is user friendly. However, insight into this concept can be gained by knowing that at the onset of the project the prosthetist knew nothing about computers and the computer scientist knew nothing about prosthetics and orthotics. This lack of knowledge about each others areas of expertise resulted in software that is familiar and natural to the prosthetist and takes best advantage of the power of the computer. For example, the prosthetist can view the model in 3D from any perspective and select the exact regions for modification by directly pointing at the model with a mouse.

Some of the other systems produce a positive mould that contains ridges. These ridges are not like traditionally smooth positive moulds produced by the prosthetists. It is presently unconfirmed whether sockets with ridges are as comfortable for the patients as the smooth sockets produced using the traditional method. While it is possible to sand the ridges and make a smooth positive mould, the process loses the numerical quantification of the socket size, shape and volume and reduces the effectiveness of this tool for determining the basic principles for socket fabrication. The milling process described produces a smooth positive mould that is as smooth as that produced by the prosthetist using the traditional procedure. No sanding is required and thus the numerical information describing the shape of the positive mould is not lost. Figure 3 illustrates a mould milled out by the NC machine and also presents a modified mould for the patient using the traditional plaster process.

When the CAD CAM research in this area originally began the task was to fit BK amputees. Hence, all the tools (i.e. mechanical digitiser, CAD software, NC milling machine) developed were designed for that task. Thus when it becomes desirable to expand to other areas these tools will have to be redesigned to accommodate different size segments (e.g. body jackets, children's prostheses). When the authors began their CAD CAM research the general objective was to develop a system to fit patients for all types of prosthetic/orthotic applications. However, it is believed that before advancing to all levels of amputation or application it was necessary to develop methods that could successfully fit patients at one level. Having solved the problems at one level will make it easier when the methods are applied to other areas. The initial test population were BK amputees. Hence the software and the milling machine were designed with that general objective in mind. The basic software is object independent and therefore is not concerned with the object's size or shape. The modifications are specific for BK sockets. However, the aspect of the software has been designed to be easily changed to the modifications required for any application. These modifications are generally based upon the markings by the prosthetists on the stump.

The new milling machine will be a five axis mill (i.e., 3 translational axes and 2 rotational axes) capable of cutting moulds necessary for all prosthetic and orthotic applications. The two rotary axes will allow for the cutting of moulds for such things as ankle foot orthoses and wheelchair seating. The mill will be able to cut a mould with a volume of up to 700mm x 700mm x 1250mm. Thus a mould of a trunk can easily be milled out for a body jacket. The feed rate of the machine will be up to 5120 mm/min to allow for the rapid cutting of the moulds. For example, at this speed a mould for a BK socket can be cut in 20 minutes.

Summary and future work

The writers have developed a numerical system for fabricating prosthetic sockets. The

system overcomes five limitations existing with some of the other numerical systems: 1) accurate high resolution surface topography, 2) specific indentification of subject modification sites, 3) flexible, user friendly software, 4) high resolution NC milling, and 5) integrated expansion to other prosthetic and orthotic areas. Fifteen patients have had trial fittings and they have subjectively stated that their "computerised" socket fits better than their traditionally made socket. Future objective evaluation of socket fit including blind fittings, independent prosthetist evaluation, pressure recording between the socket and stump, and quantification of soft and hard tissues in the stump will eventually add to the understanding of these subjective evaluations.

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CAD CAM trans-tibial temporary prosthesis: analysis and comparison with an established technique

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Abstract

The purpose of this study was to evaluate the application of CAD CAM in the production of temporary trans-tibial prostheses. The CAD CAM system was assessed based on the number of socket attempts, number of prosthetic appointments, and temporary prosthesis rehabilitation time. These parameters were considered to be related to the quality of socket fit and were influenced by the entire interdisciplinary team including the patient. A concurrent prospective comparison between the CAD CAM system and an established fibreglass/pelite liner technique was also performed. Patients (n=30), were fitted with either a conventional or a CAD CAM socket. Records were kept before and after discharge until the interdisciplinary team considered the patient ready for definitive prosthesis casting. After approximately 90 post-operative days, patients were deemed fit to proceed from their initial plaster cast prostheses to their temporary prostheses. The group fitted with conventional sockets had an in-patient rehabilitation phase of 10.5+/-60 days and required 2.9+/-1.1 prosthetic appointments. In-patients fitted with CAD CAM sockets required 5.1+/-1.8 appointments and were hospitalised for 23.6+/-15.0 days. The significantly increased rehabilitation duration and number of appointments (p=0.01), were generally due to incorrect socket volume and/or inadequately modified relief/loading areas. In this study 67% of the patients fitted with CAD CAM sockets required at least one additional attempt. The clinical evaluation and modification of the temporary prostheses, including the decision to remake a particular socket, were carried out by the same prosthetist who cast the patients. During the out-patient phase, the type of socket design was not observed to influence either duration of out-patient rehabilitation or frequency of appointments. Out-patient rehabilitation included on average 4 appointments and ended after 90 days. Multidisciplinary discharge criteria and standardised follow-up procedures rendered the measured parameters less relevant to this study's purpose in the out-patient phase.

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Introduction

Five quantitative studies of the outcome of CAD CAM fitting have been found in the literature. Topper and Fernie (1990) compared conventional sockets to sockets designed using computer aided design and manufacture (CAD CAM), in 48 trans-tibial (TT) amputees cared for by 4 prosthetists. Socket materials and sock ply were standardised. Patients were fitted and aligned with either their CAD CAM socket or their conventional one. The two prostheses were worn for as long as it was required to develop a preference, after which they were evaluated with reference to a continuous scale. After 5 CAD CAM attempts the patients were as likely to accept the CAD CAM socket as they were the conventional socket design. In another study, similar findings were demonstrated (Kohler *et al.*, 1989). A group of

five prosthetists made fittings of two patients each by conventional means. Negative casts from these patients were sent elsewhere and the CAD CAM sockets were then developed by another group of prosthetists. After fitting and alignment was completed, the patient was given both his/her CAD CAM prosthesis and his/her conventional prosthesis. The prostheses were assessed based on perceived comfort, pain, and pressure on seven occasions over a twenty day period. Seven out of eight unilateral TT patients were shown not to display a significant difference in preference between their conventional PTB and their CAD CAM socket, providing that 2 CAD CAM attempts were permitted. Earlier research, where sample size ranged from 2 to 17 patients and wearing time ranged from single fittings to 2–6 months, demonstrated moderate success with various CAD CAM systems (Krouskop *et al.*, 1987; Holden and Fernie, 1986; Foort *et al.*, 1985). Krouskop *et al.* (1987), noted that the two amputees they had studied had worn their prostheses for 6–12 hours over a period of 2–6 months. In the study by Foort *et al.*, (1985), 26 out of 36 patients were able to stand or walk for up to ½ hour with some discomfort in the CAD CAM sockets. Holden and Fernie (1986) reported findings in which 10 amputees were given prostheses with a conventional or a CAD CAM socket, and then asked to compare the two within a single fitting based on comfort. Three of the patients preferred the CAD CAM socket. In summary, studies have strived to assess the quality of CAD CAM socket design based on the opinions of the patient, in some cases comparing it to sockets produced by conventional techniques. CAD CAM sockets were worn for the duration of the experiment and not supplied to the patient indefinitely. Previous CAD CAM studies have focused on patients with mature, load tolerant, and atrophied stumps.

In order to maximise the reliability and objectiveness of the quantitative assessment, the study reported here was performed in a normal hospital setting. The prosthesis was worn for the duration of the rehabilitation period and the entire interdisciplinary team, including the patient, had an influence on socket fit evaluation. Precise total contact and aggressive loading are less critical factors in the recent amputee wearing a temporary prosthesis (Michael, 1989). Thus it was seen to be of interest to evaluate the application of CAD CAM technology under the somewhat less critical conditions of the temporary prosthesis.

The purpose of this study therefore was to evaluate the application of CAD CAM in the production of temporary TT prostheses. A comparison of the CAD CAM system to an established fibreglass socket/pelite liner technique was also performed.

Methodology

West Park Prosthetics has implemented the Applied Biotechnology (ABT) Computer aided socket design and manufacture (CASDaM) system to digitise, modify, and manufacture temporary trans-tibial (temp-TT) prostheses since August 1990. The temporal boundaries of the patient population requiring temp-TT prostheses were from when they were ready to proceed from their initial plaster cast prosthesis until they were referred for definitive casting. The study group consisted of relatively healthy amputees (n=15) with generically shaped stumps fitted with CAD CAM sockets. These patients were supervised by a single prosthetist (14 years of experience). It was found that abnormally shaped stumps (excessively bulbous, bony prominences, tibial valgus/varus), could not be successfully fitted using the CAD CAM system, regardless of the number of attempts. These patients were consequently excluded from the study. Thus stringent selection criteria were imposed which removed less than ideal patients from the study group. Patients seen within the first 3 months of the CAD CAM installation were excluded to minimise any learning influences. The study group patients were provided with a high temperature thermoplastic socket based on a plaster positive generated using the CAD CAM system. Firstly a negative cast was taken, with the prosthetist actively modifying the stump with his hands, accentuating the weight bearing areas and relieving the load intolerant surfaces. Next the negative cast was digitised using the ABT Digitform, thus transferring the socket's shape from the analogue to the digital domain. The Screenform One software package permitted digital modification of the socket to be completed. The ABT Carveform milling machine returned the digitally modifed socket

to the analogue domain in the form of a milled plaster positive. The ABT Socketform oven and vacuum system was then used to mould a high temperature thermoplastic socket over the plaster positive.

The control group represented an equal number of randomly selected patients supervised by the same prosthetist over approximately the same time period—June 1990 to January 1991. A fibreglass socket/pelite liner technique was the control standard for comparison. This technique employed the wrapping of a fibreglass casting material over a low density pelite liner. As the fibreglass wrap cured on the stump, the prosthetist actively modified the socket. Fork belt suspension, Otto Bock pylon and couplings mounted on SACH feet were used to set up both socket types.

A comparative prospective concurrent design was employed for this study. The time frame of the experiment was from the amputation until time of definitive casting. Within this continuum, a post-operative phase, an in-patient phase, and an out-patient phase were defined. During the post-operative phase primary wound healing occurred and the patient went through a series of initial plaster cast prostheses. The in-patient phase began with the first temporary casting (CAD CAM or conventional), and ended with discharge. During in-patient rehabilitation the temp-TT prosthesis (CAD CAM or conventional) was fitted and aligned to the patient. As the stump matured with respect to volume and load tolerance, sock ply was altered (3–10 ply), partial linings were added, and alignment was refined. The out-patient phase spanned the time from discharge to first definitive casting. Prosthetic follow-up after discharge ensured that the temp-TT prosthesis was safe and was still an adequate fit.

The outcome parameters compared were the number of socket attempts, the number of prosthetic appointments, and the rehabilitation time within and across the time blocks. Rehabilitation time and number of appointments were influenced by the professional opinions of the entire interdisciplinary team — including the patient. In-patient appointments were usually the result of the physiotherapist, nurse, or the clinic team reviewing the patient during rounds and identifying a prosthetic problem. The prosthetic problems were primarily due to the patients expressing discomfort or pain, skin irritation/breakdown, or as a result of improper fit. Reduced suspension, doffing-donning difficulty, changing gait patterns, and stump shrinkage also required prosthetic appointments to be made. The prosthetist involved in this study carried out the required changes and was responsible for determining whether they could be done on the existing prosthesis or if a repeat attempt was required. Finally, the prostheses were worn for up to 7 months during their temporary prosthesis rehabilitation. It is suggested that the outcome parameters of prosthetic appointments and rehabilitation time represented an objective, reliable quantitative indicator of a prosthetic device's success.

The null hypothesis was that there was no significant difference between the control and the study group for any of the studied outcome parameters. A significant difference ($p \leq 0.01$), greater or less than the control was the hypothesis being tested. If a difference of 2 appointments or 10 days was required and given standard deviations of 1.5 appointments or 7 days, then the power of the comparison would be 0.95.

Results

Table 1 lists the descriptive characteristics of the patient groups. The average ages of the control group and study group were 62.7+/-9.8 and 69.3+/- 11.3 years respectively. The cause of amputation was either due to diabetic complications or peripheral vascular disease. Control group patients were cast for their fibreglass socket/pelite liner temporary prosthesis, on average, 80.3 days after their amputation. After 103.5 days post-operatively the study group patients were cast for their first CAD CAM socket. The variability of the post-operative period in both the control and the study groups was; +/-41.8 and +/-49.8 days respectively. The patients in this study required 1 to 3 initial plaster cast prostheses, but averaged around 1.3. In summary the control and study group patient characteristics were not found to differ significantly ($p>0.20$).

In the control group none of the fibreglass sockets had to be replaced before the patients were ready for definitive casting. Sixty-seven percent of the study group required at least 1 additional attempt at fitting with a temp-TT prosthesis. Repeated socket attempts were necessary due to insufficient volume (5/15),

Table 1. Study and control group characteristics.

Control group (established technique)				Study group (CAD CAM system)			
Number (gender)	age (yrs)	post-op time int.	No. PCPs	Number (gender)	age (yrs)	post-op time int.	No. PCPs
1 (m)	50	163	2	1 (m)	72	117	2
2 (m)	67	41	1	2 (m)	76	107	2
3 (m)	66	76	1	3 (m)	73	70	2
4 (m)	70	96	1	4 (m)	84	40	1
5 (f)	69	49	1	5 (m)	68	171	1
6 (m)	70	25	1	6 (f)	50	48	2
7 (m)	66	122	1	7 (m)	65	103	1
8 (m)	62	21	1	8 (m)	77	103	1
9 (m)	70	45	3	9 (m)	74	118	2
10 (f)	68	89	1	10 (m)	72	45	1
11 (m)	69	49	1	11 (m)	54	69	1
12 (m)	64	84	1	12 (m)	49	85	2
13 (m)	47	77	1	13 (m)	81	108	2
14 (m)	36	145	1	14 (m)	58	239	1
15 (m)	66	122	1	15 (m)	84	129	2
mean	62.7	80.3	1.2		69.3	103.5	1.5
SD	9.8	41.8	0.5		11.3	49.8	0.5

Post-op time int.: number of days from amputation to first temp-TT casting.
No. PCPs: number of initial plaster cast prostheses required.

inadequately modified relief areas—especially the tibial crest, tibial tubercle, and the fibular head (3/15), or a combination of the above causes (2/15). These problems were identified by the interdisciplinary team, but the final judgement as to whether an existing socket could be modified or if a repeat attempt was required, was made by the prosthetist involved in the study.

Table 2 demonstrates the duration trends which emerged with the established technique and the CAD CAM system. In-patient rehabilitation time was less for the control group (10.5+/-6.0 days), than for the study group (23.6+/-15.0 days). Out-patient times were similarly longer for the study group than the control; 96.7+/-39.1 and 81.8+/-28.8 days

Table 2. Control and study group in-patient, out-patient, and total rehabilitation time in days.

Patient No.	Control group			Study group		
	(in)	(out)	(tot)	(in)	(out)	(tot)
1	13	62	75	41	87	128*
2	3	95	98	19	47	66
3	4	142	146	18	47	65*
4	18	74	92	25	87	112*
5	13	48	61	3	100	103
6	14	90	104	9	143	152*
7	8	118	126	52	105	157*
8	7	79	86	17	146	163*
9	12	63	75	17	110	127*
10	3	111	114	19	184	203*
11	18	64	82	13	107	120*
12	22	71	93	55	47	102*
13	1	55	56	18	112	130
14	13	37	50	10	80	90*
15	8	118	126	38	49	87
mean	10.5	81.8	92.3	23.6	96.7	120.3
SD	6.0	28.8	26.6	15.0	39.1	36.5

in: from first temp-TT casting to discharge
out: from discharge to referral for definitive casting
tot: total time temp-TT prosthesis was worn

* — additional CAD CAM socket(s) required.

Table 3. Control and study group in-patient, out-patient, and total number of prosthetic appointments.

Patient No.	Control group			Study group		
	(in)	(out)	(tot)	(in)	(out)	(tot)
1	3	4	7	6	4	10*
2	2	4	6	4	3	7
3	3	4	7	9	3	12*
4	5	4	9	9	4	13*
5	3	3	6	2	2	4
6	3	5	8	4	6	10*
7	2	6	8	5	4	9*
8	3	4	7	5	5	10*
9	4	3	7	5	4	9*
10	2	4	6	4	10	14*
11	3	3	6	3	5	8*
12	4	3	7	5	3	8*
13	1	5	6	6	5	11
14	3	2	5	4	4	8*
15	2	6	8	5	3	8
mean	2.9	4.0	6.9	5.1	4.3	9.4
SD	1.1	1.1	1.0	1.8	1.8	2.4

in: from first temp-TT casting to discharge
out: from discharge to referral for definitive casting
tot: total time temp-TT prosthesis was worn

* — additional CAD CAM socket(s) required.

respectively. Consequently total temp-TT rehabilitation time was also longer in the study group (120+/-36.5 days), than in the control group (80.3+/-41.8 days).

Similar trends were observed when the patient's rehabilitation was quantified using the number of prosthetic appointments required, as listed in Table 3. The number of out-patient appointments before definitive casting was possible did not differ significantly between the control and the study group; 4.0+/-1.1 and 4.3+/-1.8 respectively. However the number of prosthetic appointments required while the amputee was an in-patient and over the entire temporary prosthesis rehabilitation period, was significantly greater for the study group (Table 4). Control and study group in-patient appointments were 2.9+/-1.1 and 5.1+/-1.8 respectively. The total number of appointments for the control group was 6.9+/-1.0 while it was 9.4+/-2.4 for the study group.

Statistically, only control in-patient rehabilitation duration was significantly less than that of the equivalent study group (Table 4).

Recently the fabrication of the CAD CAM temp-TT prosthesis was altered to include a pelite liner. Although an insufficient number of patients have been treated in this manner to be included in this study, initial findings were interesting. Rehabilitation time, number of prosthetic appointments, and the reasons for having them appeared no different than when the pelite liner was not included. The primary advantage of the pelite liner was that doffing/donning was considerably easier—especially once partial linings were required. Furthermore, socket modification and partial linings were more easily and successfully applied, thereby increasing the longevity of the thermoplastic socket.

A group of 10 in-patients fitted with the CAD CAM system still using the Screenform One package up to 10 months after the completion of this study, were evaluated. In-patient rehabilitation required on the average, 6.3 appointments over 22.3 days. These values compare closely with what has been reported in this study. Thus the outcome parameters of this study did not appear to have been significantly

Table 4. Comparison of the control and the study group in-patient, out-patient, and total rehabilitation times number of prosthetic appointments.

Outcome parameter	p value		
	(in)	(out)	(tot)
Duration	0.01	0.30	0.05
Number of appointments	0.01	0.66	0.01

in: from first temp-TT casting to discharge
out: from discharge to referral for definitive casting
tot: total time temp-TT prosthesis was worn

changed after the prosthetist had gained more experience with the CAD CAM system.

Discussion

Due to the non-laboratory setting of this study, the subject groups could not be randomly assigned, the socket materials could not be standardised, and more than one prosthetist could not be involved in the study. However, age, gender, cause of amputation, post-operative phase, and number of initial plaster cast prostheses did not differ between the two groups studied. Furthermore, since the eligibility criteria for the CAD CAM group removed patients with irregular stumps, this would have biased the results in favour of the study group. It was not possible to unequivocally determine if the difference between the control and the study group was influenced by the difference in socket materials. The most significant difference between the two in this respect was that the CAD CAM socket did not have a pelite liner. Patients (N=6) not included in this study but treated using CAD CAM with a pelite liner did not require fewer appointments, did not complete rehabilitation any earlier, or require fewer socket modifications than the average of the study group. Independent of socket type, patients wore 3 to 10 ply prosthetic socks between the skin and the socket. Furthermore, studies which have involved control of socket materials have reported similar findings to those reported here (Kohler *et al.*, 1989; Topper and Fernie, 1990). The outcome parameters assessed to analyse the CAD CAM system and compare it to the established conventional technique were number of socket attempts, in/out-patient number of appointments and rehabilitation time. Rehabilitation time and the number of prosthetic appointments required revealed several trends. The latter was more sensitive in detecting a difference between the two subject groups. For this study patients were generally ready for their first temp-TT after 90 post-operative days. At this time the characteristics of the stump were still quite dynamic and most prosthetic appointments resulted in the fitting of partial linings, altered sock ply number, and/or alignment adjustments being carried out. CAD CAM sockets often required easing over bony prominences or custom tailored distal end pads in addition to the expected volume and alignment changes. Furthermore, 67% of the CAD CAM sockets had to be repeated. As a result of these complications the patients of the study group required on average 5 in-patient appointments and the first phase of rehabilitation lasted 24 days. In comparison the control group had on average 3 in-patient appointments and the first phase of rehabilitation lasted 10 days.

In-patient rehabilitation was not considered complete until various physical, functional, social, psychosocial, and prosthetic criteria were met. Also a standardised follow-up procedure was implemented upon discharge. These two factors tended to standardise a patient's rehabilitation with respect to duration and number of appointments after discharge. Thus it was not surprising that out-patient outcome parameters were about 90 days duration and 4 appointments independent of whether the patient was fitted with sockets fabricated using the established or the CAD CAM system.

Quantitative assessments of CAD CAM systems and comparisons to present prosthetic/orthotic techniques are useful. They provide feedback to the clinician, indicating the applications and limitations of the various CAD CAM systems. Ideally quantitative CAD CAM studies will assist prosthetists/orthotists in communicating their experience to the system designers.

Conclusions

A group of elderly trans-tibial amputees with normally shaped stumps were successfully fitted using the CAD CAM system. However, the time and number of appointments required to rehabilitate an in-patient were considerably greater than when the conventional technique was used. The CAD CAM system was evaluated based on the number of socket attempts, number of prosthetic appointments, and temporary prosthesis rehabilitation time. Thus socket design assessment relied not only on the patient's feedback during their rehabilitation, but was also influenced by the professional critique of the entire interdisciplinary team. During the prosthetic appointments it was demonstrated that more attention was required for the CAD CAM group. Besides the normally required volume

and alignment changes, CAD CAM temporary prostheses required various modifications over bony prominences and load tolerant surfaces.

Acknowledgements

The author would like to thank West Park Prosthetics/Orthotics for allowing this study to be carried out. The assistance of Ken Roczniak C.P.O., the prosthetist caring for the patients in this study, was greatly appreciated.

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Clinical comment

Psychological factors leading to amputations in adults

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Abstract

Psychological factors may lead to a small number of amputations in adults. They may be classified as being due to:

1. chronic pain syndrome;
2. artefactualists;
3. self-mutilation;
4. attempted murder.

An understanding of these potential factors will make the amputee clinic team aware of this problem, and help them deal with the rehabilitation of the patient.

Introduction

It is common knowledge that loss of a limb or limbs will lead to psychological problems, including the sequelae of grief or serious illness, i.e., denial, anger, blame, adjustment and acceptance.

Experience over the years, however, has taught the author that there are a number of psychological and environmental factors which may lead to a small number of patients being treated by amputation of a limb or limbs in adults. Hunter *et al.* (1982) reported on "mania operativa; an uncommon, unrecognised cause of limb amputation", and Hunter (1985) discussed in this journal "limb amputation and re-amputation in association with chronic pain syndrome".

With the exception of the S-H-A-F-T syndrome described by Wallace *et al.* (1978), (SAD, HOSTILE, ANXIOUS, FRUSTRATING PATIENTS who tenaciously cling to the Health Care System), there is little information on this topic in the English-speaking literature relating to amputation surgery.

Informal discussions with colleagues lead to the suspicion that this problem is not uncommon; for this reason, it is emphasised that the amputee clinic team should be made aware of the potential problems, so that they are in a better position to help in the rehabilitation of the patient.

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Classification

The author has attempted to classify these psychological factors leading to amputation (and often re-amputation) as they may present to the clinicians concerned with the care of the amputee.

Chronic pain syndrome

A relatively minor soft tissue or bone injury to the hand or foot, but commonly to the knee joint, will be followed by intensive investigations, and multiple surgical procedures, culminating in amputation of the upper or lower limb at increasingly higher levels in an unsuccessful attempt to relieve the patient's pain (Fig. 1).

Soon after the injury, there may be a prolonged and unrecognised period of reflex sympathetic dystrophy, which will contribute to the patient's ongoing disability. The patient may previously have exhibited sociopathic tendencies, and there may be ongoing drug and alcohol-related problems. It is believed that this condition merits a positive diagnosis of mania operativa, i.e. an obsession with pain and disability and the seeking of relief from this pain by repeated surgical procedures, in these cases, amputation and re-amputation of the upper or lower limb.

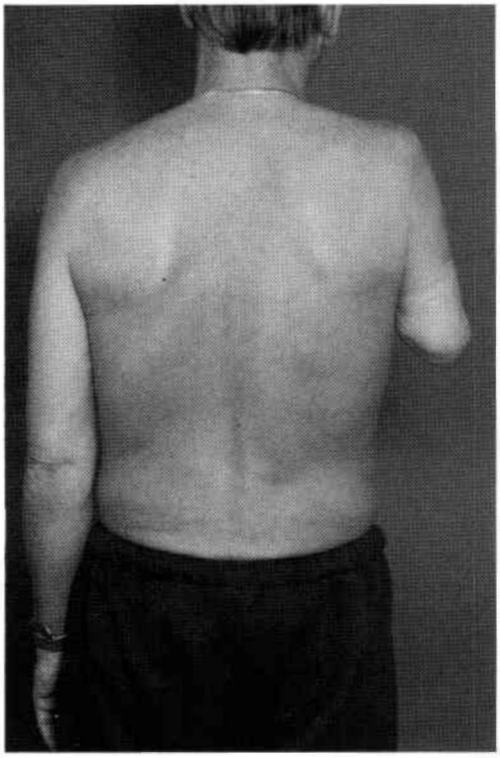

Fig. 1. Above-elbow amputation following minor injury to little finger and leading to multiple reamputations in an attempt to relieve pain.

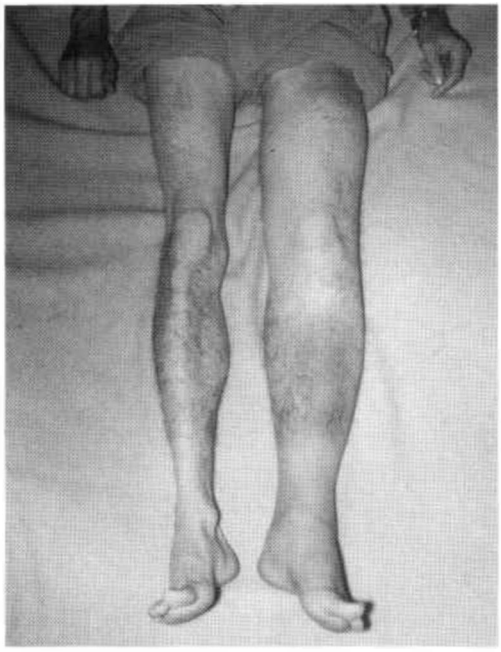

Fig. 2. Self-induced lymphoedema of left leg following use of tight bandages.

Artefactualists

Such patients will present to the clinician requesting an amputation because of sinuses, fistulae and ulcers or surgical incisions which fail to heal with standard measures; self-induced lymphoedema of the arm or leg may be caused by the use of constricting rubber bands, bandages or tourniquets (Fig. 2). The patient and the family usually deny any element of self-inflicted disease.

"Hand clenchers" should also be included in this group because poor hygiene may lead to ulceration, infection of the hand and a request for amputation (Fig. 3). Bayliss (1984) stated that dermatitis artefacta was a major problem, and may be the cause, incomprehensible to the doctor, of the amputation of fingers, a hand or an arm.

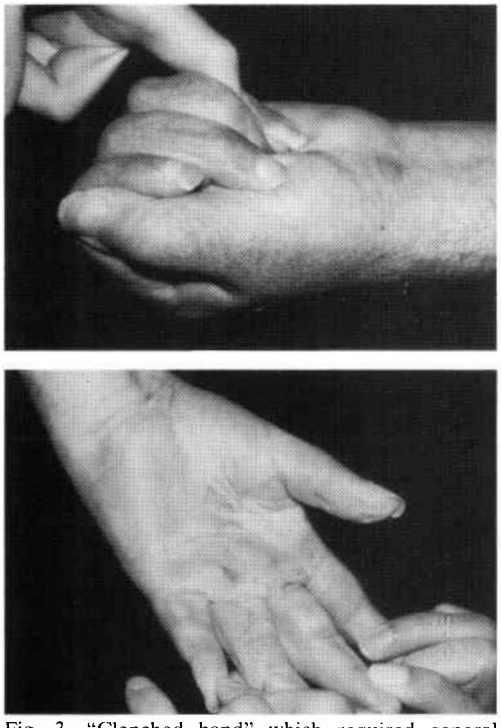

Fig. 3. "Clenched hand" which required general anaesthesia to reveal deformity.

Self-mutilation

Examples of self-mutilation seen over the years, include continued smoking, even after the loss of almost four limbs (Fig. 4), neglect of

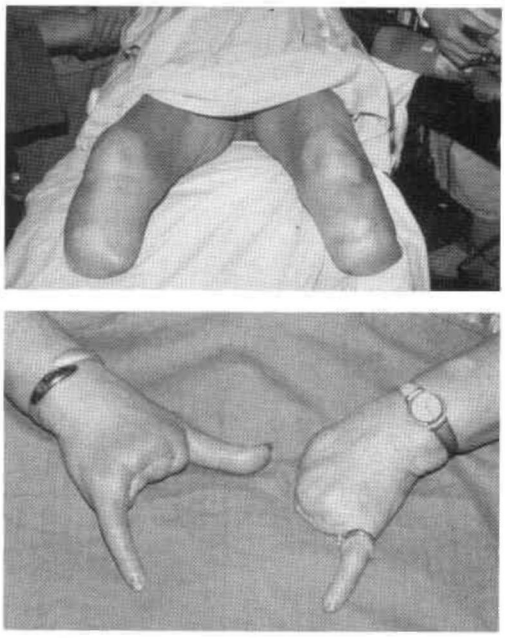

Fig. 4. Heavy smoker with severe peripheral vascular disease.

neuropathic foot ulcers, especially in the diabetic population and inadvertant self-intra-arterial injection of narcotic drugs (Fig. 5).

Alcohol and drugs are often major aetiological factors in motor vehicle accidents, bridge and subway jumping accidents and failed suicide attempts. If lucky, these so-called "accidents" result in a survivor, who is an amputee, but who still has pre-existing and ongoing psychological problems.

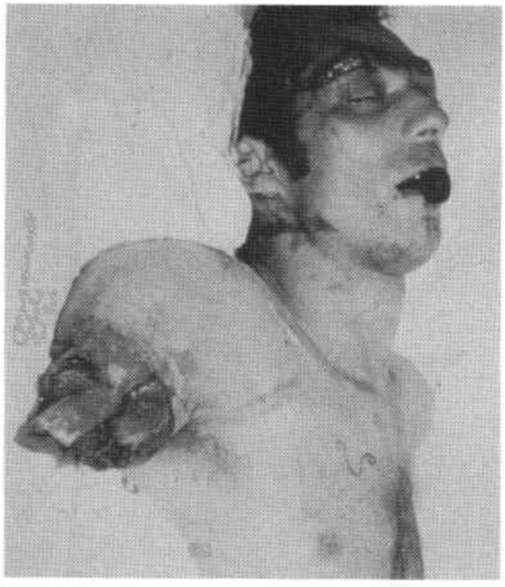

Fig. 5. Loss of arm after self intra-arterial injection of narcotic drugs.

Over a three year period between 1986 and 1989, 854 patients admitted to the Regional Trauma Unit at Sunnybrook Health Science Centre were examined for evidence of alcohol and drug ingestion. Close to 60% were found to test positive for alcohol and/or other drugs. One year after the accident, the same alcohol-positive group exhibited depression, family stress, anxiety and financial problems (McLellan, 1991: Personal Communication).

The writer has become morbidly suspicious about the relationship between psychological problems and train accidents, resulting in childhood and adult amputations. Shapiro *et al.* (1981) concluded from a review of nine adults who suffered amputation of a limb from a train accident, that the victim must be impaired by drugs, alcohol, medication or by suicidal ideas (Fig. 6).

Attempted murder

We live in a violent society and when combined with easy access to weapons, cultism,

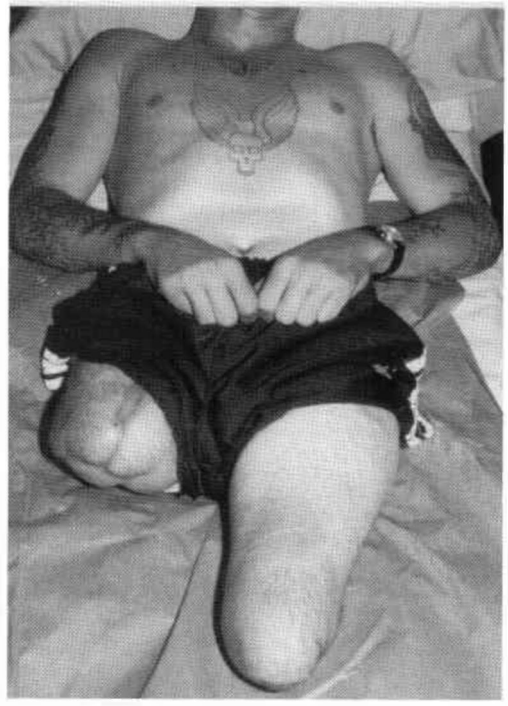

Fig. 6. Result of train accident in a suicidal patient following heavy ingestion of drugs and alcohol.

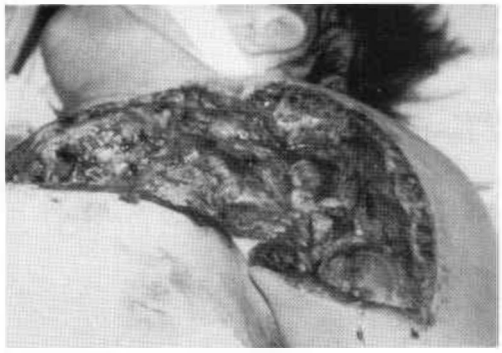

Fig. 7. Shoulder disarticulation resulted from this attempted murder with a shot-gun after a domestic dispute.

ingestion of drugs and/or alcohol and estranged family relationships, amputation of one or more limbs may result (Fig. 7.) The patient may survive the attack but limb amputation after death has been used to avoid recognition of the dead person. For various reasons, the unfortunate patient may ignore the accident or attempt to hide the identity of the assailant.

The significance of the "accident" may not be realised until exposure to the police and the court system forces the amputee clinic team to attempt total rehabilitation of the patient under the most adverse circumstances.

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Technical note

Weight distribution of below-knee amputee and able-bodied children during standing

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Abstract

The purpose of this investigation was to compare weight distributions of a relatively large number of below-knee (BK) amputee and able-bodied children during two different standing positions. Twenty-one BK amputees and 200 able-bodied children volunteered as subjects for this investigation. Each child stood on a pressure plate and three sets of trial data were collected. One set of trial data was collected with both feet together on the pressure plate and two were collected with feet placed 20cm apart. The total force applied by each foot to the pressure plate was normalised by dividing by subject weight to yield foot force to body weight ratios. Data were separated into forefoot and rearfoot areas, force for the forefoot area was then calculated and normalised by dividing by total foot force to yield forefoot to whole-foot force ratios. Ratios for the two foot placement conditions and for non-prosthetic, prosthetic, dominant, and non-dominant feet were compared using paired t-tests ($p<0.05$). Results indicated that: 1) BK amputee children placed more weight on their non-prosthetic limb than their prosthetic limb, yet this was not different from able-bodied children in respect of weight distribution between dominant and non-dominant limbs; 2) approximately 90% of the load on the prosthetic foot was placed on the forefoot; and 3) the load on the non-prosthetic foot was evenly distributed between the forefoot and rearfoot like that of able-bodied children. It was concluded that except for substantially more weight on the forefoot of the prosthetic leg BK amputee children stood in the same way as able-bodied children.

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Introduction

A previous investigation indicated that during standing, weight distribution between the non-prosthetic and prosthetic feet of below-knee (BK) amputee children and between the dominant and non-dominant feet of able-bodied children was not significantly different (Engsberg *et al.*, 1989). The study did, however, indicate significant differences between the forefoot-rearfoot weight distribution. The investigation had two shortcomings. The first was that the relatively small boundaries of the pressure plate (i.e. 19.6cm by 33.6cm) forced the children to stand with their feet together. This foot placement may not have reflected the typical or natural loading patterns of these two groups of children during standing. The second shortcoming was that the sample size of the two groups of children was small and it was questionable whether the results could be generalised. The purpose of this investigation was to compare weight distributions of a relatively large number of BK amputee and able-bodied children during two different standing positions.

Methods

Twenty-one BK amputee children volunteered as subjects for this investigation. Subject and prosthetic characteristics are presented in Table 1. Two hundred able-bodied children (104 boys, 96 girls, range 7–12 years, mean age 9.4 years, mean height = 136.8cm, SD = 12.6, mean mass = 32.3kg, SD = 9.3kg) consented to act as subjects. Table 2 presents a

Table 1. Subject characteristics of BK amputee children.

Subject Number	Age (years)	Gender	Height (cm)	Mass (kg)	Amputation	Terminal Device	Socket Type	Suspension
04	8	m	124	20	left	SACH	PTS	Condylar
05	10	f	117	19	left	SACH	PTB	Condylar
06	11	m	147	43	left	Flex	PTB	Sleeve
14	17	m	168	63	right	Flex	PTB	Sleeve
32	14	m	155	49	right	SACH	PTB	Condylar
33	8	m	130	28	right	SACH	PTB	Condylar
34	12	m	144	37	right	Seattle	PTB	Figure of eight
36	12	m	155	54	left	Flex	PTB	Sleeve
37	5	m	116	22	left	SACH	PTB	Condylar
38	5	m	113	20	left	SACH	PTB	Sleeve
39	13	m	140	37	right	Single axis	PTB	Sleeve
43	11	m	138	29	right	Seattle	PTB	Condylar
46	12	m	178	65	right	Seattle	PTB	Thigh corset
51	17	m	170	66	left	SACH	PTB	Condylar
52	11	m	130	29	right	SACH	PTB	Condylar
53	6	m	112	20	right	Flex	PTS	Condylar
54	12	f	144	32	right	SACH	PTB	Condylar
55	15	f	160	42	left	Seattle	PTB	Condylar
56	13	f	153	49	left	Seattle	PTB	Condylar
59	15	m	171	60	left	SACH	PTB	Condylar
60	7	m	113	19	right	SACH	PTB	Condylar
mean	11		142	38				
SD	(3.6)		(21)	(16)				

pediatric orthopaedic surgeon's evaluation of the condition of the able-bodied children's feet. Each child stood on a pressure plate (EMED by NOVEL GmbH) and three sets of trial data were collected. The first trial data was collected with both feet together on the pressure plate (Engsberg *et al.*, 1989). The remaining two sets of trial data were collected while the children's feet were placed 20cm apart with only one foot at a time on the plate. The pressure plate was mounted flush to a raised platform and the entire platform was covered with a cloth to prevent the child from being acutely aware of which foot was on the pressure plate.

The mean pressure of each cell was calculated from the 31 samples per trial. The amount of force applied by each foot to the pressure plate was determined for the trials and normalised by dividing by subject weight. For the able-bodied children the foot with the greater amount of force was declared as the dominant foot (Engsberg *et al.*, 1989). Pressure output was separated into forefoot and rearfoot areas. The force for each area was then calculated and normalised by dividing by total force from that foot (Engsberg *et al.*, 1989). The resulting ratios (i.e., foot force to body weight ratios and forefoot to whole-foot force ratios) for the two standing conditions and for non-prosthetic, prosthetic, dominant, and non-dominant feet were compared using paired t-tests ($p<0.05$).

Results and discussion

Figure 1 shows the pressure plate results for the ratios of foot-force to whole body weight for the BK amputee and the able-bodied children for the two foot positions. For the BK amputee children the results indicated that significantly more weight was placed on the non-prosthetic foot than the prosthetic foot. However the same trend existed for the dominant and non-dominant feet of the able-bodied children. It should be noted that no significant differences

Table 2. Foot evaluation of 200 children by pediatric orthopaedic surgeon.

Foot type	Pronation and Cavus						Pes Planus		
	Pronated		Cavus		Normal	Total	Pes Planus	Normal	Total
	Mild	Moderate	Mild	Moderate					
Number of Subjects	87	24	3	1	85	200	43	157	200

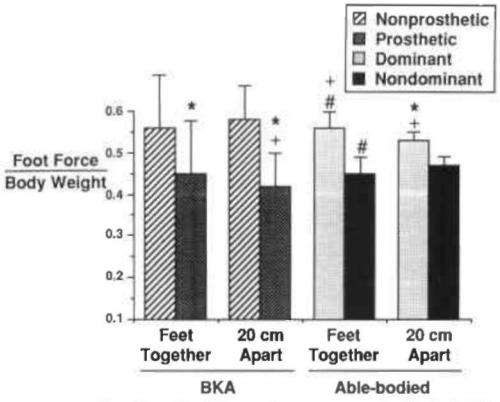

Fig. 1. Foot force to body weight ratio for the feet of BK amputee and able-bodied children.

existed between the able-bodied girls and boys and between ages, and all data were grouped together. Futher, by definition of the dominant foot, the results indicated more weight was placed on the dominant foot than the non-dominant foot. However, it was not by definition that the differences were significant. The results comparing the non-prosthetic feet to the dominant feet and the prosthetic feet to the non-dominant feet were not significant for the "feet together" position, but they were for the wider foot placement. Finally, the "feet together" position was significantly different from the "20cm apart" position for the able-bodied children. The results of the present investigation are in agreement with those previously reported for a smaller cohort of subjects (Engsberg *et al.*, 1989).

Figure 2 presents the ratio of forefoot force to whole-foot force for the two different foot placements. A forefoot force to whole-foot force value of 0.5 would describe a case in which weight was evenly distributed between forefoot and rearfoot areas. This was the case for the non-prosthetic leg of the BK amputee children and the legs of the able-bodied children. A value greater than 0.5 would indicate more force as applied to the forefoot than the rearfoot. Such was the case for the prosthetic foot where approximately 90% of the force on the foot was applied to the forefoot and only 10% was applied to the rearfoot. No significant difference existed between the foot placements. The forefoot to whole-foot ratio for the prosthetic foot and the dominant and

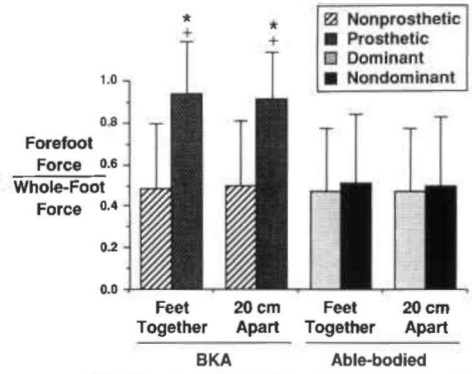

Fig. 2. Forefoot force to whole-foot force ratio for the feet of BK amputee and able-bodied children.

non-dominant feet of the able-bodied children agree with those previously presented. However, the forefoot to whole-foot force for the non-prosthetic leg do not agree. In the previous investigation about 33% of the force was on the forefoot and 67% on the rearfoot. In the present investigation the force was about evenly distributed and the same as that of the able-bodied children.

Conclusion

BK amputee children have significantly greater loading on their non-prosthetic leg compared to their prosthetic leg. Yet this is not different from that of able-bodied children in respect of dominant and non-dominant legs. Thus, except for substantially more weight on the forefoot of the prosthetic leg, BK amputee children stand the same as able-bodied children. In addition, the same results are obtained for the BK amputee children whether they stand with their feet together or with their feet 20cm apart.

Acknowledgment

Funding provided by The Hospital for Sick Children Foundation and by the Variety Club of Southern Alberta – Tent 61 through the Alberta Children's Hospital.

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ENGSBERG JR, ALLINGER TL, HARDER JA (1989). Standing pressure distribution for able-bodied and below-knee amputee children. *Prosthet Orthot Int* **13**, 152–155.

Prosthetics and Orthotics International, 1992, 16, 203–205

Education feature

A training and development concept for the field of Orthopaedic Technology

S. HEIM

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Introduction

For many years now there has been no doubt as to the need for a course of training which is comprehensive and above all structured and appropriate for the conditions of each individual country. It has finally been realised that a professional development process requires a specialised foundation.

In Germany the specialised/professional development in technical orthopaedics did not take on clear contours until 1880, when vocational training became controlled by law. By that time it had become necessary to take into account the growing demands of the industrial development process and society's need for social security. The introduction of the training vocation of "orthopaedic mechanic" and the creation of a vocational image made orthopaedic technology attractive, career-oriented and capable of expansion.

Consequently, countries in which the need for orthopaedic care exists, but which lack structured vocational development and therefore a career pattern, have no, or only little, opportunity to develop the necessary orthopaedic care structure in a sustainable manner. Short-term aid campaigns, such as the secondment of an orthopaedic treatment expert or donation of orthopaedic appliances, usually survive only as long as they are backed by external support, guaranteeing finances as well as vocational and specialised assistance.

As the executing organisation of Technical Co-operation of the Federal Republic of Germany with other countries, the GTZ has, in addition to a current crash aid programme, incorporated this realisation into its development projects in the orthopaedics sector.

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A professionally recognised foundation resulted in social standing and prospects for the future which were the logical godparents of today's training system for "orthopaedic technologists" or, as identified by the ISPO and WHO the Category II professional.

Even today, very often the Category II professional must replace the CPO, the "Meister" (master craftsman), in many parts of the world. For many reasons, this person often does not exist at all in the countries of the Third World or, if he does, can only be available for training measures. Furthermore, the social aspect of orthopaedic treatment for the physically handicapped is not to be ignored. The orthopaedic technologist must be prepared for the fact that, in most countries, the social worker, so necessary for the work with the handicapped, does not exist and therefore the orthopaedic technologist must often take over his work, too.

Today's training, the form and contents of which have been undergoing constant adaptation in recent years, is the result of the recognition of this situation and takes into account the changing demands related to various development stages and cultures.

The entrance requirement

Completion of at least ten years of general education is the prerequisite in almost every country for further vocational qualification and its subsequent recognition and social classification. Hence:

> successful completion of ten years of school (equivalent to the German "Mittlere Reife") is an entrance requirement for all GTZ training schemes.

Duration and content of the training

The training is based on a balanced interplay of scientific and practically oriented segments:

- of the 1330 periods of instruction per year approximately 800, i.e. about 60%, are practically oriented.
- focal segments such as biomechanics, pathology and workshop technology underline the practical application.

It must also be pointed out that, unless other topics dominate in certain countries, the GTZ focal areas of training generally lie in the treatment of the lower limbs. It is seen as a central task of the training to impart the skill in producing and fitting the appliances for the individual patient — giving due consideration to the necessary handling and management skills.

Training sequences

During the three years the following training is carried out:

- 1st year: basic training in metal/plastics processing, orthotics techniques.
- 2nd year: wood and plastics processing, prosthetics techniques.

For both years the clearly defined learning targets and contents for the necessary theoretical instruction are described in detail right down to the individual instruction periods.

- 3rd year: According to a catalogue of compulsory topics, the students perform treatment in orthotics, and in prosthetics, under the guidance and supervision of the practical instructors.

The remainder of approximately 200 instruction periods can be used for optional exercises as needed, and possibly for specialisation. The theoretical instruction in this year serves the purpose of accompanying and supporting the practical instruction.

Contents and demands of the final examination

The contents and demands of the final examination reflect the future tasks of the "orthopaedic technologist". In addition to the conventional examinations of knowledge in the theoretical subjects, the focus here is on knowledge in the practical area of application:

- the candidate makes two appliances,
- takes measurements from the patient,
- fits the appliances to the patient,
- and submits the finished appliances to the examination team,
- together with:
  a clinical assessment, an illustrative technical drawing, and a realistic calculation of costs.

The demands placed on a professional in the Third World countries are often more comprehensive and more extensive than those placed on his colleagues in an existing and functioning technical environment.

Unless a course of training takes these facts into account, its result will fall short of the expectations. A comparative study has shown that the learning targets for "orthopaedic technologists" are more comprehensive in many sectors than, for instance, those for their German counterparts.

International recognition

The final examinations in the individual training centres should be compatible with those found in other systems and training courses. This is essential for students aiming towards further training as a Category I professional in order to improve their qualifications. Until now, the training projects of the GTZ have been tied to the German system in order to permit further training to "Meister" if necessary and when possible. For this reason, all the examinations held included a certain number of external examination questions and were marked by external examiners.

However compatibility always has its limits and often requires very great additional efforts. The writer now believes that the training should be more international. The international professional organisations are called upon to continue on a hitherto successful path and to create a professionally oriented examination for "orthopaedic technologists" and, if the candidate passes the exam, to guarantee him the professional title and recognition.

GTZ has proved at their various training centres that training contents and the imparting of knowledge can be steered by the examination contents.

As a result of all this work a specialised, practically oriented final examination has also been developed. This structured final examination is offered as the foundation for the

necessary specialised international examination for "orthopaedic technologists", the Category II professional.

Expectations and perspectives

It is intended to use the same, examination-oriented philosophy in future for the further training of the orthopaedic technologists to Category I professional. The experience to date in the further training of the graduates from Third World countries in established systems, e.g. in Germany, tends to be frustrating and far from satisfactory. Although more than 60 specialists from Africa, Asia and Latin America have qualified as "Meisters" in Germany in recent years, the efforts are often extremely great and are out of proportion to the result.

In addition, some of the subjects which have to be learnt within the futher training are often totally unrelated to the demands placed on the profession in the various home countries. The writer therefore suggests that:

- ISPO/INTERBOR draw up an examination profile and examination regulations for the Category I professional.
- an international "Certification Board" hold and recognise examinations for candidates from all countries.
- the technical competence and the right to use the professional title be certified and recognised for the individual candidate after passing the examinations.

Such a step would be future-oriented, enhance development and is therefore urgently needed. GTZ will bear this path in mind for future activities in the training sector and incorporate it in the activity profiles of the projects.

Prosthetics and Orthotics International, 1992, 16, 206–210

Education feature

Ten years in the development of the Tanzania Training Centre for Orthopaedic Technologists

W. RAAB

TATCOT, Moshi, Tanzania

Introduction

The unique Tanzania Centre for Orthopaedic Technologists (TATCOT) for the English speaking countries in Africa, celebrated its 10th anniversary in 1991.

The German Technical Co-operation Agency (GTZ) laid the foundation stone of this remarkable development in Orthopaedic Technology on the 26th August, 1981 with the arrival of the first two expatriate teachers.

The decision of the Ministry of Health, Tanzania with the co-operation and support of the Federal Republic of Germany, to build the Tanzania Training Centre for Orthopaedic Technologists, is today rewarded with an enormous increase in the profession in Tanzania itself and the other English speaking African countries.

The Project

After an 18 month construction period TATCOT was able to celebrate its official opening in July 1983 under the leadership of GTZ expatriate Orthopaedic-Engineer and recent Vice President of ISPO, Sepp Heim.

Remarkable results could be shown by this date:

- the school and workshop were completed and installed.
- the three years training programme was running smoothly.
- the first and second years' trainees had completed their exams.
- it was possible to offer and conduct workshops, short term courses and seminars on international level.

The development of TATCOT then progressed as follows:

May 1984	International workshop on "Education, training and clinical services in prosthetics and orthotics technology for developing countries".
June 1984	First group of 14 students completed their three years' training course.
January 1985	First recognition of the course by the International Society for Prosthetics and Orthotics (ISPO).
July 1985	Construction of students' hostel and staff houses.
November 1985	Seminar on "TATCOT establishment and future plans in Tanga".

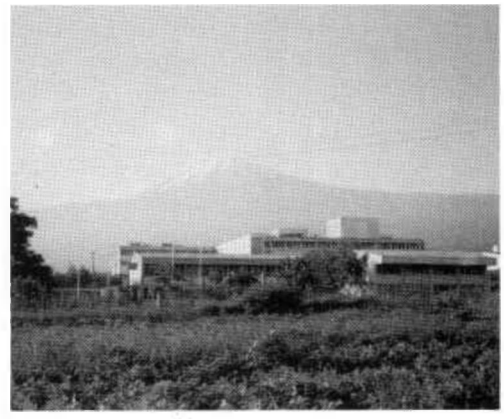
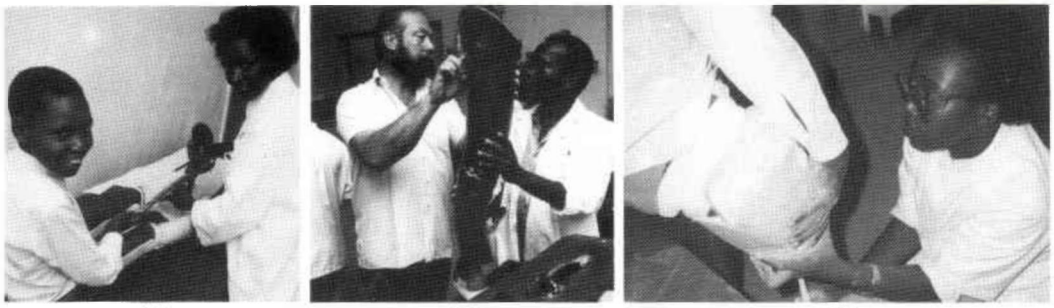


Fig. 1. TATCOT school building and Kilimanjaro Regional Medical Centre.

All correspondence to be addressed to W. Raab, TATCOT, PO Box 8690, Moshi, Tanzania.



(a) (b) (c)

Fig. 2. a) Fitting knee-ankle-foot orthoses for poliomyelitus.
b) Instruction during field work practice.
c) Fitting a plaster model for an above-knee socket.

March 1986	Senate of the University of Dar-es-Salaam approved the training and examination regulations for the diploma in Orthopaedic Technology.
June 1988	First group of 12 students were awarded diploma of the University of Dar-es-Salaam.
July 1988	Regional Seminar held on "Rehabilitation and training of lower cadres".
December 1988	Completion of the local component production unit.
July 1991	Exhibition at Dar-es-Salaam "International Trade Fair".
October 1991	Review of the curriculum.
January 1992	Training programme for a one year course in lower limb orthotic technology (LLOT) established and training facilities completed ready to commence.

Further activities planned for 1992 are:

- Regional seminar on "Poliomyelitis".
- Participation at ISPO World Congress in Chicago.
- Exhibition at Dar-es-Salaam "International Trade Fair".
- 17th World Congress Rehabilitation International participation in co-operation with the International Society for Prosthetics and Orthotics (ISPO).

Fig. 3. Training in the design of prosthetic/orthotic components.

The three years training course

The development of the training contents for the three years course was influenced through the large experience of GTZ in establishing and operating service units and training centres in Tunisia and Togo.

The conclusion of these experiences was that, in order to meet the demand of the disabled population in Africa, a thorough training in theory and practice was needed to produce a well-trained independent working Orthopaedic Technologist. The course content of the TATCOT course is summarised in Table 1.

The well trained professional produced by this course should have;

- the necessary theoretical and practical skill

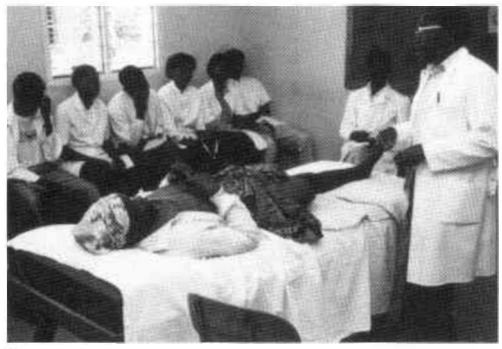


Fig. 4. Instruction as a clinic team member.

Table 1. Course content.

First year training	
Practical (72.4%) — General mechanical skills — Production of arch supports — Production of lower limb orthotic components and elements — Production of lower limb orthoses.	Theory (27.6%) — Anatomy and Physiology — Technology — Biomechanics — Mechanics — Mathematics — Technical Drawing — Introduction to Health Delivery Systems and Primary Health Care concepts.
Second year training	
Practical (76.3%) — General mechanical skills — Production of lower limb prosthetic components. — Production and fitting of lower limb prostheses. — Production and fitting of lower limb orthoses. — Production and fitting of spinal and upper limb orthoses.	Theory (23.7%) — Anatomy and Physiology — Technology — Biomechanics — Mechanics — Mathematics — Technical Drawing
Third year training	
Practical (75.5%) — Ankle-foot orthoses — Knee-ankle-foot orthoses — Other orthoses — Foot prostheses — Below-knee prostheses — Above-knee prostheses — Other prostheses	Theory (24.5%) — Functional Anatomy — Pathology — Biomechanics — Clinics — Workshop Management

to give a high standard of service to patients;
- the potential of teaching and training others in more advanced techniques of orthopaedic rehabilitation.

The orthopaedic technologist trained at TATCOT, is expected to participate in rehabilitation in the following areas:
- as a full member of the clinical team;
- in the provision of orthotic/prosthetic appliances;
- in the administration and management;
- in new developments concerning orthotics and prosthetics;
- in lecturing and demonstration to colleagues, community and government groups and others professionally concerned with orthotics and prosthetics.

This very high demand on the performance of the qualified TATCOT graduate needs a very close follow-up and support through the training centre, to enable the former student to use her/his knowledge in the new professional environment. TATCOT therefore puts in a great effort, to intensify contact with its former students and offers services such as:
- upgrading seminars and workshops;
- short term courses;
- school information;
- consultancy services.

Summary

The aspirations of TATCOT to form international links with important orthopaedic technology training institutions has resulted in an intensive co-operation with the
- Bundesfachschule für Orthopaedie Technik, Dortmund, Germany

and the
- National Centre for Training and Education in Prosthetics and Orthotics, University of Strathclyde, Glasgow, Scotland.

The solid and thorough training and the seminars and workshops at international level conducted at TATCOT has led to the good reputation which the centre enjoys.

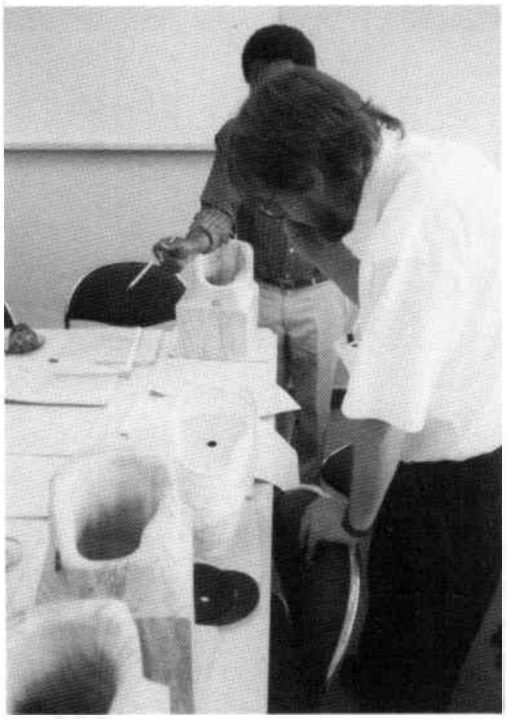


Fig. 5. External examination of third year practice.

After 10 years of operation and existence TATCOT believes that it can be proud that it has achieved its aims.

A tracer study, recently carried out TATCOT displayed that in Tanzania, East Africa and other English speaking African countries, the Tanzania Training Centre is in very high demand to produce more Orthopaedic Technologists, to conduct more seminars and workshops, to enlarge the consultancy services on an international level and to research more in the production of components.

Future

As can be seen from the list of students (Table 2) some 140 Orthopaedic Technologists trained at TATCOT have returned to their home countries. It is very important to offer a modern training and adapt it to the demands and development of the different countries.

Besides the three years' training course and the one year "Lower Limb Orthotics Technology" course, the school is operating a production unit for locally made orthotics/ prosthetics components. This unit was

Table 2. List of students 1981–1991

Country	Students
Tanzania	34
Zimbabwe	24
Kenya	14
Zambia	13
Ethiopia	11
Uganda	9
Malawi	6
Liberia	4
Pakistan	4
Madagascar	3
Sierra Leone	3
Botswana	2
Gambia	2
Nigeria	2
Seychelles	2
South Africa	2
Swaziland	2
Lesotho	1
Somalia	1
Germany	1
Total	140

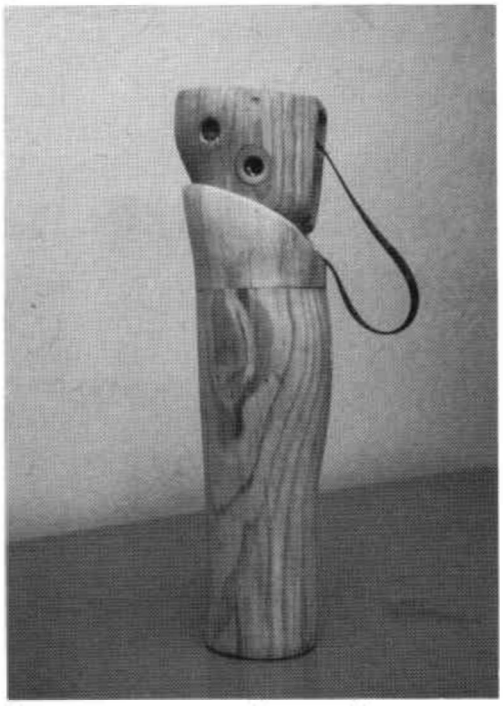


Fig. 6. Local production of knee components.

established with the intention of producing components which would minimise the cost of an orthopaedic appliance and be more appropriate to the environment. The fabrication of components in the production unit on a large scale will also reduce the time spent by students at present on the production of appliances. This should allow more time in the third year of the course for training in the evaluation of patients' needs and individual assessment for prescription of appliances.

If TATCOT succeeds in assisting with the establishment of functional operating workshops for the manufacture of orthopaedic appliances in the rural areas, it would be one important step towards the improvement of the Rehabilitation Services in the English speaking African countries towards the year 2000.

Application for admission at TATCOT three years training

For further information on how to apply for Orthopaedic Technology Training at TATCOT and the approach for obtaining the necessary financial assistance, please write to the:

Principal of TATCOT,
P.O. Box 8690,
Moshi,
Tanzania.

Fig. 7. Orthopaedic workshops are contributing to the aim of improving rehabilitation services in English speaking Africa.

Prosthetics and Orthotics International, 1992, 16, 211–212

ISPO Update Course on
Lower Limb Amputations and Related Prosthetics
Compound Fractures and the Neuropathic Foot

8th–12th March, 1993
Moshi, Tanzania

Introduction

The format of this second **update course** following the Consensus Conference in Glasgow, October 1990 will be **review lectures** based on the presentations at the consensus conference and the points from the discussions leading to contemporary recommendations. Consideration will also be given to the treatment of compound fractures.

Ample time will be allocated for elucidation and discussion with the participants. The course is aimed at orthopaedic surgeons, general surgeons, rehabilitation specialists, prosthetists, orthopaedic technologists and other members of the amputation team.

Venue

TATCOT, Kilimanjaro Christian Medical Centre, Moshi, Tanzania.

Course Fee

The course fee is US$50 which covers lectures, Consensus Conference Report, coffee, tea and lunches.

Accommodation

Accommodation can be arranged at Uhuru Hostel, Moshi at a cost of US$20 per night.

Per Diem

It is estimated that a subsistence of at least US$15 per day is required over and above Registration and Hostel costs.

Transport

By plane to KIA (Kilimanjaro International Airport). Local transport between KIA and Moshi will be arranged on receipt of travel information. It should be noted that there is an Airport Tax of US$20 payable when leaving Tanzania.

Sponsorship

Prospective participants are encouraged to seek sponsorship from local offices of such agencies as Ministry of Health, Ministry of Social Services, British Council, World Health Organisation and any other local agencies.

Registration Form

Mail to ISPO, National Centre for Training and Education in Prosthetics and Orthotics, University of Strathclyde, 131 St. James Road, Glasgow G4 0LS, Scotland. Bank drafts should be made payable to ISPO.

(continued over)

Name _____
Male/Female (Delete as appropriate)
Mailing address _____

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Institution address _____

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Tel: _____ Fax: _____
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Profession: _____

I wish to attend:

Update Course ☐
Seminar ☐
I require accommodation in Uhuru Hostel ☐
Expected date of arrival _____
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Registration Fee for Update Course U$50
Payment enclosed as bank draft ☐
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