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An "appropriate technology" trans-femoral prosthesis, using materials available in Nepal

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Abstract

The use of western components and materials for prostheses is prohibitively expensive in most developing countries. In addition, local customs and conditions vary considerably from those for which the prostheses were designed. For these reasons, a trans-femoral prosthesis has been developed in Pokhara, Nepal, using entirely locally available materials, and with a view to fulfiling local requirements as far as possible.

This paper describes the materials and fabrication technique for the component parts of the prosthesis, the local conditions for which it was developed, and a three year follow-up of the first prosthesis issued. Only one serious design fault was discovered during this period, and a modification to the fabrication procedure introduced. The authors believe that if this trend continues, this style of prosthesis may be useful in the future for Nepali amputees and perhaps also in other countries, particularly where mass production of components is not practical.

Introduction and local conditions

The Himalayan kingdom of Nepal is a landlocked country, situated between Tibet in the north and India in the south. The country divides into three areas: the high mountains to the north, the plain in the south and the hills in between, where Pokhara is located. In this area travel is mainly by foot, some villages being several days walk from the nearest motorable road. In addition to porters, pack ponies are used to transport goods, but it is fairly unusual to see people on horseback. Travel often involves wading across rivers which are sometimes waist deep during the rainy season. Paths are stony and often steep, although many people live on land where the immediate environment around the home is flat.

Much of life in Nepal takes place at floor level. Cooking, washing, eating and toileting are usually carried out sitting or squatting on the ground. Inability to do this is clearly a handicap in Nepali society. Piped water is available only in some homes, the majority of households relying on water carried from a nearby source by the women. Small children are traditionally strapped to the back of their mother or carried on the hip. Nepal is essentially reliant on subsistence agriculture, with the result that many people carry out manual work in the fields. In the hilly areas, both barefoot and shod walking are commonplace, with canvas shoes being preferred in the cooler climates. Footwear is generally removed on entering a home or a place of worship. Generally, both men and women wear long clothes covering their legs, though it is socially acceptable for male manual workers to wear shorts. For the above reasons, it is important for prostheses in Nepal to be durable, waterproof, and able to be repaired locally as far as possible. It is also important that the amputee can reach floor level comfortably, and for women, particularly, to be able to carry loads, like water and children. Cosmesis, on the other hand is not so critical as it would be for western women wearing short skirts. Ideally, a prosthesis should be able to be worn with or without shoes, with the footwear being easily removable.

The use of entirely locally available materials in the prosthesis described here (Fig. 1) ensures that major maintenance can be carried out in the hospital where it is made, while minor repairs

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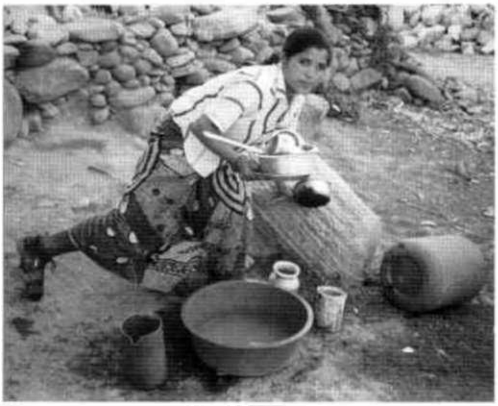

Fig. 1. The first prosthesis is being used at the home trial stage.

can be carried out by shoe-makers anywhere in the country. Standard biomechanical and functional principles are used in the design.

Thermoplastics have been introduced into prosthetic and orthotic production in developing countries in the last few years (Fago, 1992; Meanley, 1991; Moll, 1991; Oberg, 1991; Ortholetter, 1993, 1994 and 1995; Theuvenet *et al.*, 1994; Garachon, 1996). In the prosthesis described here, durability and water resistance are addressed by the use of High Density Polyethylene (HDPE), which is available as drainage piping in Nepal.

Film canisters may seem to be a more western commodity, however, as tourism is the country's biggest foreign currency generator, the photographic industry is well advanced, and such accessories plentiful.

Although the SACH foot has neither the cosmetic appearance nor the mobility of the Jaipur footpiece (Sethi *et al.*, 1978; Sethi, 1989), it requires little maintenance, is cheap and easy to make from materials available in Nepal.

The cycle axle knee, based on a design by Girling and Cummings (1972), also allows for easy access to replacement parts. The knee permits up to 100° of flexion which, while insufficient for deep squatting, does enable the amputee to reach floor level with ease.

The suspension

The suspension of the prosthesis is a combination of suction and a modified Silesian belt. The belt has the standard pivot attachment to the lateral wall of the socket and a buckle or double D-ring attachment anteriorly. In addition to the pelvic band giving suspension over the contralateral iliac crest, a lateral band passes from the posterior over the ipsilateral iliac crest to a D-ring at the mid-line anteriorly and from there to the anterior buckle attachment.

The belt is made from water buffalo leather, and the pelvic band lined with softer goat leather. The lateral band and anterior D-ring are joined to the pelvic band with speedy rivets, and both attachments to the socket are made with 4mm diameter nuts and flat headed bolts. The heads are smoothed and the bolts are trimmed to length. They are inserted from the inside of the socket, and once the belt and nut are in place the cut end is hammered to prevent the nut from coming loose. The belt is reinforced with metal washers between the layers of leather wherever a hole is punched for a speedy rivet or bolt.

The knee

The knee is based on a design described by Girling and Cummings (1972). It is a single axis joint with adjustable friction control, and uses the front axle and hub of a bicycle as its main components.

The proximal and distal blocks are fabricated from a medium density wood *(Mangifera Indica)* and are finished with a waterproof varnish for protection against water and insects. The proximal block is made from three wooden components and houses the axle, hub, extension stop bar and friction adjust bolt. The wooden blocks are shaped to give a similar appearance to exoskeletal knees which are commercially available in the west.

The extension stop bar is fitted to the axle, and bears on the inner surface of the distal block, preventing hyperextension. When the friction adjust nut is tightened, it moves a leather block, which bears through the extension stop bar onto the axle, thus increasing the friction in the system. A double piece of tailor's elastic with a leather tab at either end is used anterior to the knee to provide an extension assist.

The foot

The SACH foot made in Pokhara is by no means unique to Nepal (Girling and Cummings, 1972). It is made from a local hard wood (*Shorea Robusta*) and microcellular rubber (MCR). It is attached to the ankle block with a nut and bolt.

A hole is drilled for the attachment bolt, an countersunk distally to allow room for a socket wrench and the nut. The lateral pattern is then drawn on the wood block and the anterior and posterior wedges cut from the distal surface. After smoothing the surfaces a laminated MCR wedge is glued to the heel section and a shaped MCR sole piece to the plantar surface of the foot block.

Saw cuts are made from the proximal surface to the top of the lateral pattern, the base of these cuts marking the extent of the wood to be removed proximally. Finally the foot is shaped and smoothed in three dimensions and a countersunk hole made in the rubber heel.

The socket

The socket is made from HDPE pipe and uses a film canister for pull sock access and air seal. It is a suction socket and is used as partial suspension for the prosthesis. Until now a quadrilateral design has been fabricated, although this technique could equally be used for an ischial containment socket.

A hand cast is taken of the stump, and the positive model modified in the normal way. A length of pipe is split so that it will open flat when heated in an oven. Precautions are taken to prevent it collapsing in on itself. Once it is hot and soft, the plastic is stretched over the model and sealed on the lateral side. The surface is rubbed with cloth and smoothed into the concave areas of the model. These areas are then packed with cloth and the socket wrapped tightly with elastic bandage.

Once it is cool and contact between the plastic and the model is ensured, the socket is trimmed and the edges finished. A hole is made antero-medially to accommodate the film canister. The base of the canister is removed and the remainder is glued into the hole. Finally, the edge of the film canister is smoothed where it contacts the amputee.

Assembly and finishing

To assemble the prosthesis from its component parts, the following procedure is followed:

Ankle and shin blocks are cut from a light soft wood (*Bombyx Malabaricum*) measuring 120mm x 120mm. Their total length is calculated using the height of the sound leg from the heel to the top of the knee in sitting. The ankle block is drilled and countersunk to allow for the attachment bolt of the SACH foot. The ankle block is then bolted to the foot, with the nut distal. The proximal end of the bolt is prevented from rotating within the block by pouring a mix of polyester resin and sawdust into the countersunk hole.

The measurement from the ischial shelf to the proximal end of the knee in extension is calculated using the ground to ischial tuberosity measurement of the sound limb. Another block of soft wood is cut and hollowed out to seat the socket at the required height.

The socket is set in the proximal soft wood block with a sawdust and resin mix, and aligned with the posterior and medial shelves horizontal. The prosthesis is then assembled and aligned according to standard principles. The height and shelf alignment are checked and the blocks joined with wood glue. Once the glue has set, the wood block joints are also stapled to reinforce them during trial use. The suspension belt is attached, and the prosthesis is checked with the amputee for comfort, alignment and friction control of the knee.

Once necessary adjustments have been carried out, the prosthesis is ready to be finished. First, the thigh and shin sections are prepared for the plastic cosmesis. The proximal and distal blocks of the knee are disconnected, the suspension belt removed, the SACH foot unbolted and the staples removed. The shin and thigh sections are shaped on a router, with additional microcellular rubber or cork added to increase the bulk as necessary. The film canister is removed from the socket and replaced with a cylindrical wood block. Then the socket is filled with plaster of paris and a mandrel inserted. This prevents the socket being misshapen when the outer plastic cover is applied.

HDPE pipe is split and heated as in the socket fabrication technique, and pulled round the thigh and shin sections. The plaster of Paris is removed from the socket and the edges of the cosmeses trimmed and smoothed. The canister is re-inserted in the socket and the proximal edges of the socket and thigh cosmesis welded together using a heat gun and strips of HDPE pipe. The cosmesis is smoothed and the distal end of the thigh cosmesis screwed onto the proximal block of the knee. The holes for attachment of the suspension belt are then drilled in the cosmesis.

HDPE pipe is only available in black in Nepal, so the prosthesis is coloured by glueing nylon stocking onto the exterior of the cosmesis with neoprene cement, and then painting it with a mix of wood glue and fabric paint. Finally, the elastic extension assist and suspension belt are re-attached. The finished prosthesis weighs approximately 2.5kg and has an appearance which has proved cosmetically acceptable to amputees and relatives alike.

Optional knee lock

To date, a total of seven prostheses of this design have been issued at Green Pastures Hospital. One of the amputees concerned lives in an extremely hilly area, and also had a trans-tibial prosthesis on her contralateral leg. To provide her with greater stability, a manual knee lock was fitted on her trans-femoral prosthesis (Fig. 2).

The lock was a length of spring steel bar, with a right angle bend 10mm from one end. The bar was passed through slots cut in the proximal block of the knee, and ran posterior to the extension stop bar. By bearing on the extension stop bar, the knee lock prevented knee flexion. This could be inserted or removed manually, the right angle bend allowing for greater purchase on the bar. A leather sheath screwed to the side of the shin section housed the lock when not in use.

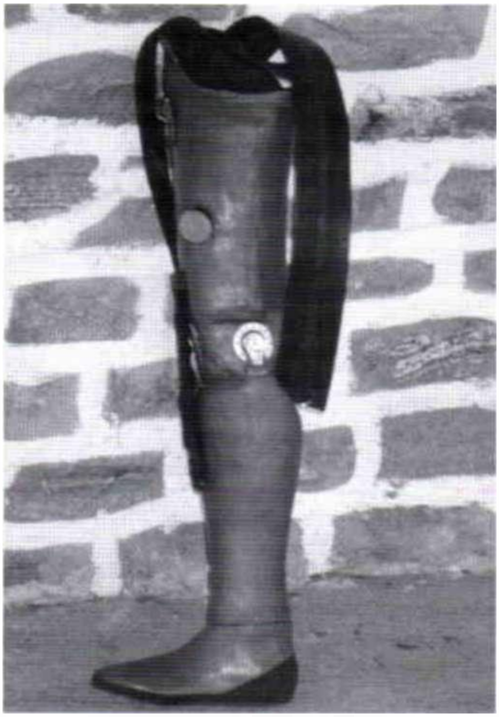

Fig. 1. The finished prosthesis.

Follow-up

The first prosthesis made to this design was fitted in March 1994. Although the authors acknowledge that prostheses should ideally be tested in laboratory conditions first (Day, 1996), this was not possible in the setting described. The first prosthesis was therefore issued to an established amputee who was young, strong and highly motivated to make maximum use of it, often carrying loads of up to 15kg of water or young children. She was intelligent and fully understood that this was a trial design. She lived locally to the hospital where the prosthesis was fitted, and was easily able to return should any problems arise. She was very enthusiastic to take part in the trial. Below is a follow-up report of this prosthesis:

At the first fitting, a regular Silesian belt slipped distally, so a lateral strap was added. Knee flexion was insufficient to allow floor sitting, so this was increased to 100°. Both these became standard techniques for subsequent prostheses.

After 6 weeks, hospital trials were complete and the prosthesis was finished and issued for home trial (Fig. 3).

After 3 months, the stump had shrunk and suction was lost, so the socket was padded to compensate for this. The elastic extension assist had stretched and was replaced with double high quality elastic in this and later prostheses. The side bars of the knee had worked loose so were set in resin to re-attach them. Subsequent knee joints were made with side bars attached to the distal block with nuts and bolts.

At 4 months, further stump shrinkage necessitated more socket padding. Later amputees were fitted with a temporary prosthesis and given walking training to induce shrinkage prior to the fabrication of the definitive limb. The extension stop rubber in the knee was worn, resulting in audible contact at full extension. This was replaced with rubber covered with leather, and subsequent knees were made with this modification. The leather suspension belt had stretched, and additional holes were punched so that the belt could be tightened.

After 7 months, the film canister was split as a result of repeated stress from the pull sock. This was replaced with as little of the canister protruding as possible to ensure maximum support for the thin plastic. There was damage to the periphery of the rubber sole of the SACH

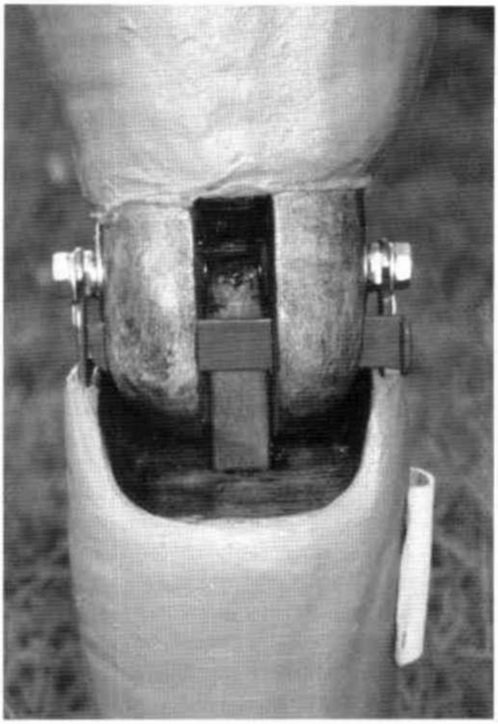

Fig. 2. Optional knee lock used for bilateral amputee.

foot. This was replaced and bevelled to give a better fit in the shoe. Damage to the posterior thigh of the cosmesis was repaired with leather. There was also some wear of the proximal block of the knee from contract with the distal block during extended floor sitting.

At 9 months there was further stretching of the suspension belt lateral strap. Subsequent prostheses used a double D-ring attachment anteriorly to allow for easy compensation for stretching of this strap. Other minor damage was repaired on the belt and socket attachments.

At 12 months there was a crack down the posterior of the shin cosmesis, further damage to the periphery of the rubber sole and a torn socket attachment all of which were repaired.

After 2 years of constant wear, the suspension belt and rubber sole had been replaced again, as had the film canister, which had split. The shin piece had been repaired, and due to a fall, the extension stop bar had broken. This was replaced with a hard wood bar. The amputee had lost weight, and was losing suction in the socket, so padding was added.

During the third year of use, apart from replacement of the extension stop and sole rubber, it was necessary to repair the wood glue joints between the different wooden blocks. This was considered to be a serious fault, and all joints between the wood blocks were reattached with a resin and sawdust mix, as this form of adhesive between the socket and the thigh block had shown no signs of weakening over the three years of use.

Conclusions

In conclusion, no major design faults were discovered during the two years of use of this prosthesis, however the wood glue connections were not strong enough to last a third year, so a resin and sawdust mix was used for these joints in subsequent prostheses. Apart from this, minor repairs and replacements of belts, the elastic extension assist and the sole rubber were necessary. These could have been carried out by a local shoe-maker if the amputee had not had access to the prosthetics facility. The extension stop bar was replaced with a harder wood to reduce the likelihood of a repeat failure. The amputee herself reports that this prosthesis compares favourably with the second hand prosthesis with which she was previously fitted. She continues to use it constantly, and lives a life not dissimilar to many other Nepali people with no physical impairment.

The results of this follow-up are encouraging, and as this is continued, and appropriate modifications made if necessary, it is hoped that the fabrication of this style of prosthesis will be useful for Nepali trans-femoral amputees in the future.

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