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Vulcanized rubber foot for lower limb amputees

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Introduction

A prosthetic workshop was started some years ago at the S.M.S. Medical College Hospital, Jaipur, to meet the growing demands of the local population. Unlike the premier limb-fitting centres in India which still cater for the more affluent sections of society, it was decided that this centre would also look after the poor rural amputees. It soon became apparent that a disturbing number of amputees from the villages were unhappy with their prostheses and discarded them after their initial enthusiasm waned. No flaw could be detected in the fabrication or fitting of these limbs to account for this rejection. An enquiry was then instituted to find out the reasons for non-acceptance of these prostheses. Several factors emerged out of this study.

Shoes and Indian amputees

The average rural Indian does not wear shoes. He has to walk on a rugged terrain and through water and mud. This is not kind to shoes which break down with a frequency which the urban population cannot imagine. Even the urban amputees do not wear shoes inside their homes, in the kitchen and in places of worship. On formal occasions footwear frequently takes the form of an open sandal, this practice being related to the hot climate where closed shoes are uncomfortable. Shoes not only raise the initial cost of a limb considerably but the frequent need for renewal imposes a financial burden which most amputees find impossible to meet. In short, the requirement for a shoe to be worn with a lower limb prosthesis raises economic and cultural problems and it was felt that the shoe should somehow be dispensed with.

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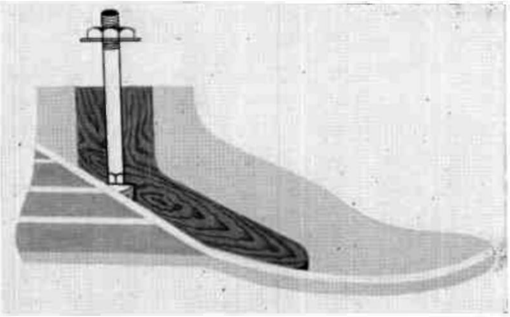

Fig. 1. The SACH foot, see text.

Once the outer casing formed by the shoe is removed, the bare footpiece is revealed to the onlooker and it therefore becomes important to give it the shape of a normal foot for obvious psychological reasons.

The SACH foot

The functional design of a conventional footpiece also posed some problems. For instance, it is customary for Indians to squat (sitting on haunches) or sit cross-legged on the floor. Squatting requires a range of dorsiflexion which is scarcely available in a single axis ankle joint and totally absent in a SACH foot (Fig. 1). Sitting cross-legged on the floor is a complicated manoeuvre. The forefoot rests on its outer border and is deflected into adduction, together with an element of supination twist; the hindfoot is inverted. A SACH foot has a rigid keel which does not allow this freedom of movement and if an amputee tries to sit cross-legged on the floor with a SACH foot, a combination of a twist and adduction strain is transmitted via the shank to the socket and an unbearable pressure is felt on the stump. When it is realized that social etiquette as well as the majority of vocations involve sitting or squatting on the floor, it was felt that this matter also needs to be looked into.

There are other objections to a SACH foot. This foot was designed for amputees walking on level ground and the rather limited range of inversion and eversion by compression of the heel pad has so far been considered adequate for the Western amputee. It is when SACH feet are used in rugged terrain for rough outdoor activities that their structural and design weaknesses are revealed. Even in the West, where the material used for SACH feet is far superior to that used in Indian SACH feet, complaints of frequent breakdowns have been voiced by amputees who want to lead a vigorous outdoor life (Harris, 1973).

The presence of a rigid keel does not permit any transverse rotation of the foot in relation to the leg; the importance of this movement is receiving increasing recognition in recent descriptions of gait analysis. But more important than any of the foregoing drawbacks is the inability of the foot to adapt readily to uneven surfaces. The ground reactions are transmitted and magnified by the length of the shank to the stump, consequently many amputees felt very uncomfortable when walking on rough and uneven ground.

Peg legs and rural amputees

The general philosophy of most Indian surgeons has been to follow a double standard. For the well-to-do urban amputee who can take to a Western style of living, that is walking on level ground, sitting on chairs and using Western type of toilet seats, a conventional prosthesis is provided. For the poor rural amputee a peg leg is prescribed. While it is true that a peg leg is simple and inexpensive, even the rural amputee of today would reject it on cosmetic grounds. In addition, there are numerous biomechanical drawbacks which are commonly overlooked. The point of support is too small; a peg leg sinks in sand or mud. The impact of heel-strike cannot be cushioned adequately because of the lack of an ankle and knee mechanism (Saunders, Inman and Eberhart, 1953). The forward transfer of the point of support from the heel to the metatarsal heads which is so necessary for knee stabilization during take-off is not possible in a peg leg; an above-knee peg leg prosthesis cannot have a knee mechanism. The inability to shorten and lengthen the limb during the gait cycle leads to a characteristic vaulting gait (Murphy, 1960).

Formulation of objectives

Based on the foregoing observations, the requirements of the footpiece were roughly formulated as follows:

1. It should not require a shoe, and consequently, should have a certain degree of cosmetic acceptance by the amputee.
2. The exterior should be made of a waterproof, durable material.
3. It should allow enough dorsiflexion to permit an amputee to squat, at least for short periods.
4. It should permit a certain amount of transverse rotation of the foot on the leg to facilitate the act of walking as well as to allow cross-legged sitting.
5. It should have a sufficient range of inversion and eversion to allow the foot to adapt itself while walking on uneven surfaces.
6. It should be inexpensive.
7. It should be made of materials which are readily available.

Muller solid rubber foot

Muller, working in Ceylon, was faced with the problem of providing limbs for amputees working in paddy fields with legs immersed in water. His major objective was to render the prosthesis waterproof. He chose vulcanized hard rubber for this purpose and used it to cover the wooden leg piece (Muller, 1957). A solid L-shaped prolongation simulating a foot was added to improve the function of the limb. One can conceive of the Muller limb as a large skin-tight gum boot in which the shoe portion was replaced by a solid rubber footpiece (Fig. 2). This was an improvement on the peg leg and Muller expressed considerable satisfaction with his design.

Muller's choice of vulcanized hard rubber as a material for a footpiece appeared to be very apt. Natural rubber has a combination of several properties which, in many ways, is unique. Its durability, resilience, resistance to abrasion and to cuts and tears are not present in any of the available plastics. Moreover, natural hard rubber is readily available in India because of an extensive trade in retreading worn out automobile tyres. Almost every town in India has retreading shops and local craftsmen know how to handle this material.

Fig. 2. Muller foot with solid rubber footpiece. The footpiece offers biomechanical advantages over a peg leg.

The first step in this project was therefore to borrow Muller's idea but improve on its appearance. A plaster of Paris replica of a normal foot was made and a die was prepared from it (Fig. 3 top).

Rubber was packed into the die and vulcanized by heating it in an oven. A foot such as is shown (Fig. 3 bottom) was obtained.

While the cosmetic features of this solid rubber foot were quite pleasing, it was too heavy and very stiff and it lacked the selective resilience and rigidity at appropriate places which are desirable in a foot and ankle mechanism.

Rubber enclosed SACH foot

In order to make the foot lighter, a SACH foot was placed in the die and enclosed in hard rubber, a much lighter foot with all the desirable design features of a SACH foot was obtained (Fig. 4). This foot was like having a built-in rubber shoe over a SACH foot with the external appearance of a normal foot. The external hard rubber enclosure served as a protection as well as a screen to the underlying SACH foot. While this footpiece was considerably lighter than a solid rubber foot, the compressibility of the heel pad was diminished because of the much stiffer hard rubber enclosure.

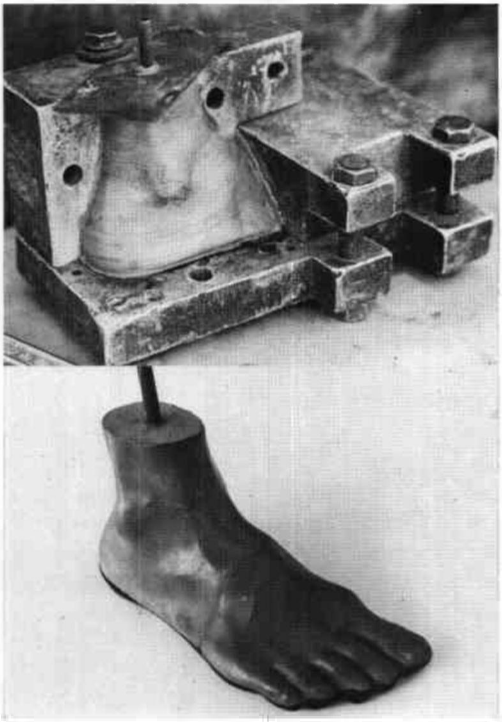

Fig. 3. Top, die prepared from plaster replica of normal foot. Bottom, cosmetically acceptable footpiece of solid rubber.

Mid-tarsal break

Having achieved the initial requirement of dispensing with the shoe, and providing a footpiece with acceptable appearance, durability and being waterproof, the objective of allowing an amputee to squat was pursued. The solid wooden keel of a SACH foot does not allow any dorsiflexion. To allow this movement a wedge was removed from the keel, based dorsally and located approximately in the mid-tarsal region. The space created by the removal of the wedge was filled with a soft grade of sponge rubber. It was argued that a closure of this wedge would simulate dorsiflexion. However, when a foot with this mid-tarsal break was used, only a very limited range of dorsiflexion was achieved. Apparently the size of the wedge was too small. Also, the foot bent at the wrong place; it was odd to witness an amputee develop a rocker-bottom foot while trying to squat.

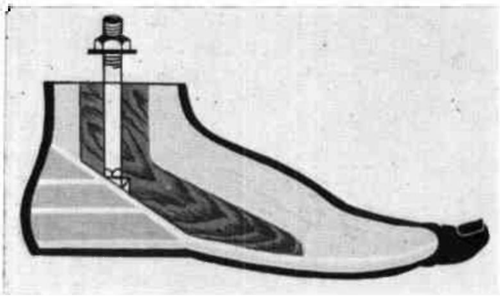

Fig. 4. Rubber enclosed SACH foot, see text.

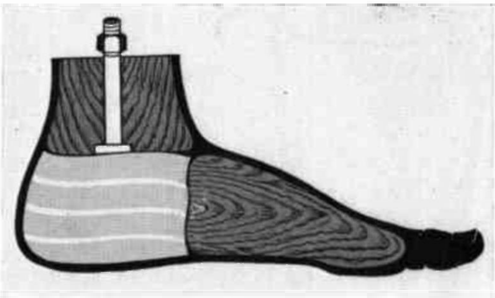

Fig. 5. Initial design of Jaipur foot.

Evolution of the Jaipur foot

Efforts so far had been concentrated on developing the design of the SACH foot to provide additional ranges of movements. Larger and larger wedges were removed till almost nothing was left of the proximal section of the keel where the carriage bolt for fixing the shank to the foot could be securely held.

It was at this stage that a total departure was made from the SACH foot and a completely new design was worked out (Fig. 5). The solid wooden keel was dispensed with. Instead, two completely separate wooden blocks were used. A proximal wooden block, which roughly represented the lower end of tibia, was used for securing the carriage bolt. A distal wooden block occupied the area normally represented in a foot by the distal row of tarsus and the metatarsals. The intervening space was filled with layers of sponge rubber, glued together. This represented the mobile section of the ankle, subtaloid and mid-tarsal joint complex. This large sponge rubber block could now act as a universal joint with freedom of movements in all directions. Dorsiflexion, plantarflexion, inversion, eversion, abduction and adduction were all possible. In addition the foot as a whole could now rotate on the leg.

Initial mistakes

A number of initial mistakes were made. In our first attempt the proximal wooden block was placed directly over the sponge rubber block. This resulted in the wooden block sinking at every step and the sponge rubber was quickly damaged. To protect the sponge rubber, a platform or shelf of hard rubber was interposed between the proximal wooden block and sponge rubber. While this succeeded in protecting the sponge rubber, the interface between the distal wooden block and the sponge rubber developed a pseudarthrosis because of stresses accumulating at this joint (Fig. 6 left). Gradually, the idea of enclosing the entire sponge rubber block in a closed shell of hard rubber emerged (Fig. 6 right). This protects the sponge rubber so effectively that we have had no subsequent structural failure of this region in spite of gross abuse of the footpiece by farmers over a period of years.

In order to allow free dorsiflexion, too much sponge rubber was used and the amount of hard rubber in front of the ankle region was deliberately thinned out. This permitted the amputees to squat with ease but led to instability in walking, where, during the latter half of the stance phase the leg would suddenly buckle forward, causing an excessive flexion of the knee. The gait resembled a typical calcaneus limp. We had then to curb our enthusiasm and pack in more hard rubber in front of the ankle to control instability in walking.

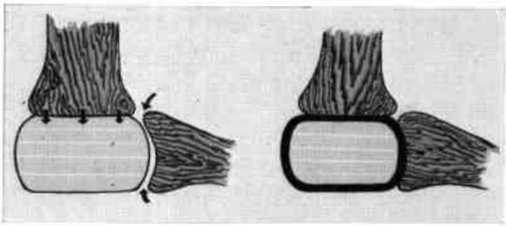

Fig. 6. Left, the proximal wooden block sinks into the unprotected sponge rubber causing damage during weight bearing. Right, enclosure in a shell of solid rubber protects the sponge rubber block; no subsequent structural failures have been encountered.

Reinforcement by cord lining

To determine the strength of these feet, loading tests were conducted in a universal testing machine and the foot was found to break at a vertical loading of two tons. This was felt to be a satisfactory figure. However, when field trials were held, a number of amputees came back with cracks which were mainly located around the distal edge of the proximal wooden block. There was apparently a concentration of stresses in this region and the wooden block gradually worked its way through these cracks. It was then suggested that reinforcement with cord lining should be used as is done in automobile tyres. The various structural components of the foot were bound with a cord lining (Fig. 7). The breaking load figure rose to a value of six tons. Further field trials were conducted and the locations of these cracks were carefully plotted. These vulnerable areas are specially reinforced and now these feet are really strong and durable.

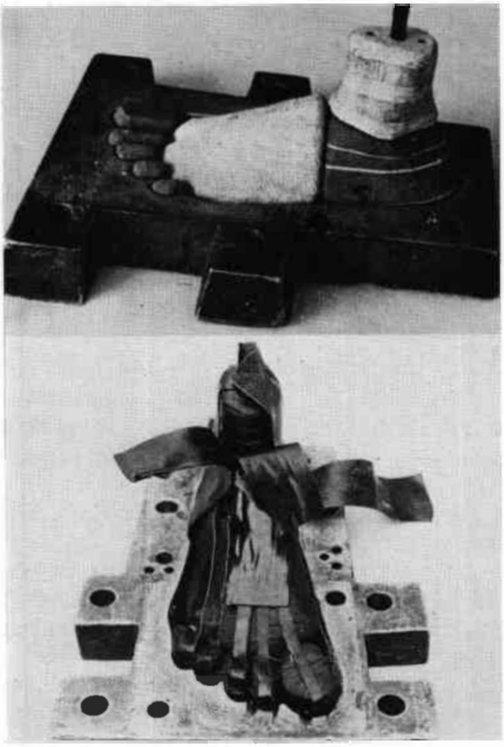

Fig. 7. Top, components of the Jaipur foot. Bottom, rayon cord, used in automobile tyres, reinforces and binds the components. Structural failures are now rare.

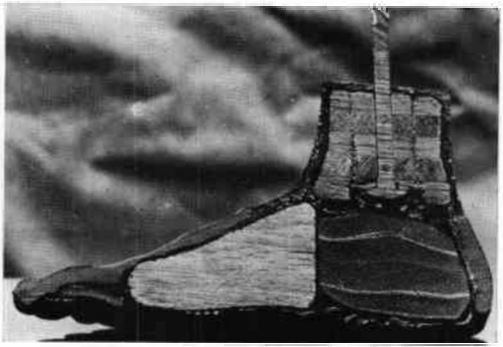

Fig. 8. Jaipur foot. Note the laminated proximal wooden block. The lighter colour of the dorsal surface is provided for cosmetic reasons; it is made of soft, resilient, lightweight cushion compound. The dark sole is made of tread compound to provide toughness and durability.

Analysis of present design

Figure 8 shows a sagittal section of the footpiece which has been finally adopted. It can be seen that the overall structure reproduces broadly the basic functional components of the human foot.

Initially the toes were made of solid hard rubber and these sometimes fractured. The toes are now filled with sponge rubber inserts which not only provide a soft cushion-like feel but also render them more resilient and less liable to break away. Usually the individual toes are not separated, it being unnecessary cosmetically and functionally. A slit, however, is provided between the great and the second toes to allow insertion of the strap of a sandal if the amputee desires to wear one.

The space normally occupied by the distal row of tarsal bones and the metatarsals is represented by a single wooden block. This provides rigidity to the forefoot which is so essential for an efficient take-off. As compared to the wooden keel of a SACH foot, the anterior limit of the forefoot is located further distally where normally the metatarsal heads lie. The roll-over is much more natural and theoretically speaking, knee stabilisation should be more effective.

The main function of the proximal wooden block is to provide anchorage for the carriage bolt. There is no movement of the carriage bolt in a SACH foot because the wooden keel is a one-piece structure. In the present design, however, the carriage bolt moves with the wooden block in various movements. There must be some stresses generated around it since in many of our earlier feet, the wooden block split along the grain of the wood around the bolt. Hence this block is now made by joining several pieces of wood with their grains at right angles to each other, based on the principle in plywood. This enormously strengthens the structure and no further breakdowns have been encountered.

The sponge rubber universal joint is the most important design feature of the foot. Several layers of sponge rubber are glued together to form this large block. The entire block is enclosed securely in a closed shell of hard rubber. It is a self-contained unit and very simple to fabricate. In addition to providing freedom of movement in all directions, it is noiseless, requires no lubrication and no structural failure has so far been encountered.

During the course of this study, skiagrams were taken to demonstrate the structure of the foot and to study its behaviour during different movements (Fig. 9). The first skiagram revealed that the different layers of sponge rubber, which were so carefully glued together, had come apart. Apparently the heating during vulcanization had caused the glue to give way. This was a little unsettling and a search began for a suitable heat proof adhesive. However, while studying the movements in a cut section of the foot, it was apparent that because of this separation these layers were able to glide on each other, thereby adding to the overall mobility. In other words, the unwitting separation of these layers during vulcanization

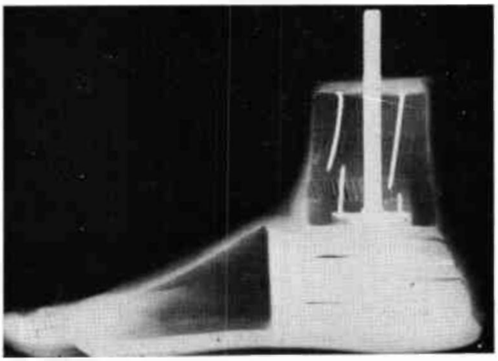

Fig. 9. The separation of the layered structure of the sponge rubber joint is shown in this skiagram, see text.

actually conferred an advantage. To prove the point, a sponge rubber block made out of a large single piece of identical material was used in a foot and the mobility was shown to be significantly reduced.

Another advantage of these separate layers seems to lie in the dissipation of stresses along the lines of cleavage, thereby protecting the sponge rubber from breaking up. An analogy of the joints which are deliberately made when laying a concrete floor to allow cracks to be dissipated along these joints can be offered.

External vulcanized hard rubber enclosure

A layer, approximately 2 mm thick, of hard rubber covering encloses the main structural components of the footpiece. In the initial stages of this work too much hard rubber was used; this increased the weight of the foot and also reduced its suppleness. Suitably coloured, this vulcanized rubber exterior offers a durable and waterproof cover of acceptable cosmetic appearance. While the rest of the foot is enclosed in a softer, lighter and more resilient grade of rubber, known as rubber cushion compound, the sole is made of a tougher material which is used on the external facing of an automobile tyre, known as rubber tread compound. This tread compound has far greater resistance to abrasion, tears and cuts but is stiffer and heavier. Its use is therefore restricted to the sole of the foot and can be compared to the thick plantar skin of a normal foot. The cushion compound is then comparable to the thinner skin of the non-weight bearing areas of the foot.

Observations

These feet have been tested in the laboratory as well as in field trials over a period of eight years in more than a thousand amputees.

The cosmetic features are satisfactory. The amputees are pleased with their appearance and from a distance it is difficult to detect that the foot is artificial. When new, the foot looks a little shiny and smooth but with use, the surface acquires a matt finish and wrinkles appear which, with a layer of dust which inevitably covers it in barefoot walking, gives it a very realistic appearance. The problem of colour matching exists. Three shades of coloured rubber have been used to match dark, medium and fair skinned individuals and this seems to serve the purpose reasonably well. The use of waterproof paint was tried; a more pleasing colour matching could be achieved but the paint started peeling in a few weeks. While repainting could be done by the amputees themselves, there is little doubt that coloured rubber offers a much better solution.

These feet are heavier than conventional SACH feet. There is no reason why this drawback cannot be overcome by rubber technologists. It must be made clear, however, that the combined weight of a SACH foot with the overlying shoe is more than this rubber foot.

The feet are durable; some farmers have

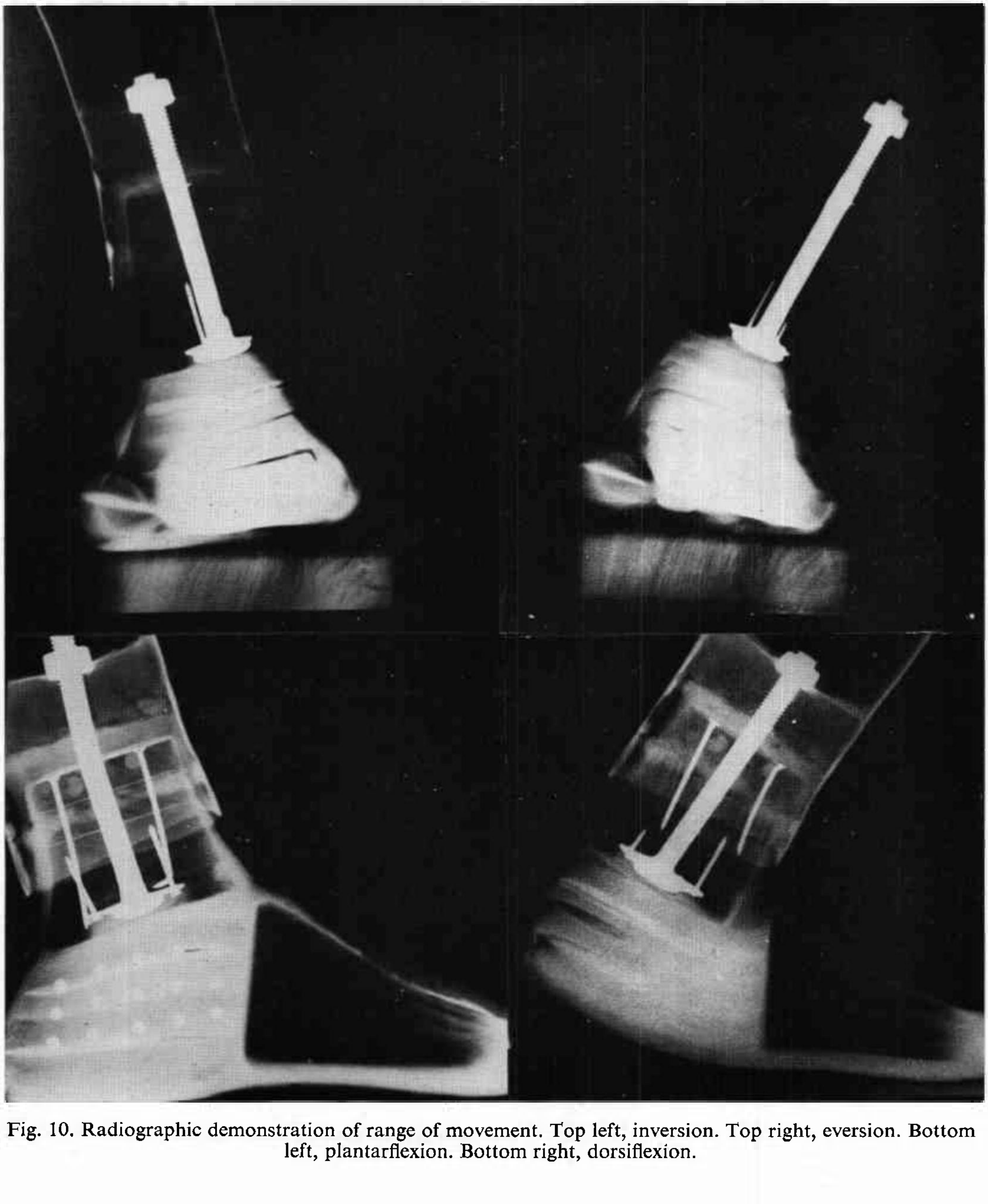

Fig. 10. Radiographic demonstration of range of movement. Top left, inversion. Top right, eversion. Bottom left, plantarflexion. Bottom right, dorsiflexion.

been using them in the environment of Indian villages for as long as 3 years without breakdown. The addition of a cord lining has significantly increased the strength as well as the durability.

The cost of production is reasonable. The initial expense of making a die is soon nullified by the number of feet which can be produced. With the current cost of labour and raw materials in India these feet cost only about £2.00 (sterling). This is as much as a pair of shoes would cost to the amputee.

There is some freedom of movement in all directions. The skiagrams reproduced here (Fig. 10) show the range of movement, with the carriage bolt utilized as an indicator.

The advantages of having a universal joint became apparent in our field trials. The amputees can sit cross-legged on the floor comfortably; no discomfort is felt in the stump as is the case when SACH feet are used (Fig. 11 top). Squatting is possible because of the range of dorsiflexion available (Fig. 11 bottom). There was an apprehension that this range of dorsiflexion might lead to a feeling of insecurity, especially in above-knee amputees. This, however, is not so. If one observes an amputee with this foot during the process of squatting, a very interesting fact emerges. The initial phase of squatting is carried out slowly, as if the foot is not yielding into dorsiflexion. As the effort continues, the foot is found to yield increasingly easily and the last phase of squatting is performed smoothly. This feature is based on the property of hard rubber which bends slowly at first but as the deforming load persists, the curve of bending rises steeply. This explains why, in spite of possessing a range of dorsiflexion which can allow squatting, there is no feeling of insecurity in ordinary walking; the small range of dorsiflexion needed in the gait cycle meets with a fair degree of resistance.

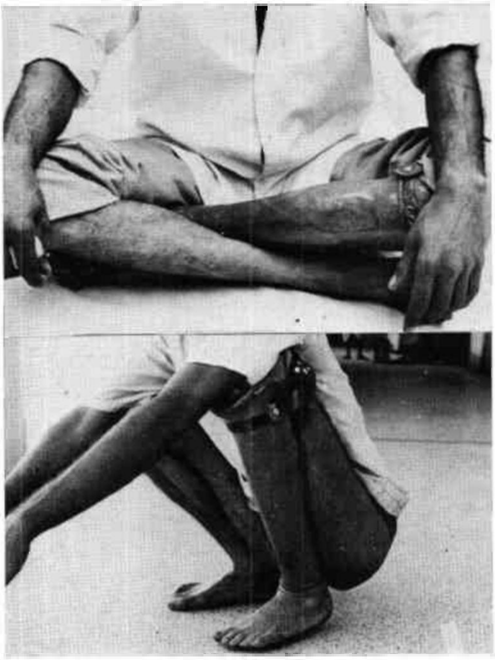

Fig. 11. Top, the range of inversion and adduction of the foot allows cross-legged sitting. Most Indians adopt this position at work. Bottom, the range of dorsiflexion permits squatting.

Walking on rough ground is performed remarkably well. The foot adapts itself readily to uneven surface with the result that the ground reactions are not easily transmitted to the socket-stump interface. To compare the performance characteristics of a SACH foot to the present design in a rugged terrain, an experiment was conducted. Two identical feet were prepared, one having a SACH foot inside and the other having the present design with a universal sponge rubber joint. The patient chosen for the trial was an intelligent farmer. He was asked to use each foot during his outdoor work and his subjective reactions as well as the condition of the stump were recorded after a day's work. The limb having an enclosed SACH foot was found to be very uncomfortable and the stump, at the end of the day, was painful and bruised. With the present design, no adverse reaction was noticed.

Transverse rotation

The significance and value of transverse rotation of the leg in relation to the foot during the gait cycle is being increasingly realized. Lamoreux and Radcliffe (1977) reiterated the need to incorporate this movement in lower limb prostheses and presented a new design to allow passive rotation of 20 degrees in either direction with a centring spring—the UC-BL axial rotation device. The Jaipur foot provides the same range of rotation in either direction.

Pneumatic joint

In an attempt to reduce the weight of the foot, it was suggested that instead of containing layers of sponge rubber, the hard rubber housing of the joint should be left hollow. It would then resemble a closed rubber ball containing air and could reasonably be labelled as a pneumatic joint. The idea seemed attractive and a foot was constructed and fitted to an amputee. It was observed that while the heel strike was very comfortable, the amputee felt a recoil on the stump when the heel was lifted off the ground. This was presumably due to the property of bounce which air conferred on this joint. The compressed heel expanded too rapidly when pressure was removed and the thrust was transmitted proximally. Thus another valuable property of sponge rubber was revealed; slow controlled recovery after deformation.

Weight bearing surface

A rather surprising observation was made that the amputees felt very secure in these feet from the beginning and required almost no gait training. The limb was fitted and they walked off. This was in contrast to our earlier experience with SACH feet where it took some time for the amputee to learn to walk confidently. This appears to be related to the very large area of support offered by these feet. A walking foot print is almost indistinguishable from a normal human foot print (Fig. 12). A SACH foot, on the other hand, has a solid ankle and requires a rockered sole for a smooth heel to toe gait. A

Fig. 12. Left, a walking foot print reveals the large weight bearing area of the Jaipur foot. Right, compare the sole of the normal foot with a Jaipur foot which has been used for some months; such a broad flat sole is only successful if there is mobility available at the ankle.

Fig. 13. The adaptability of the foot permits tree climbing; this is a valuable asset in rural India.

rockered sole provides a relatively small area of support and consequently the amputee requires to learn to balance himself on it. For Indian villagers the ability to climb trees is also an important asset and amputees fitted with the Jaipur foot have had no difficulty in performing this feat due to the grip afforded by the rubber sole and the adaptability of the foot (Fig. 13).

Maintenance and repairs

There are no metallic joints which require maintenance. Being made of waterproof material, the feet can be washed daily without harm. The colour is built-in and no fading occurs with time.

Some feet develop superficial cracks. These are seen less often now since the incorporation of a rayon cord lining. Most are in any case attributable to faulty fabrication, since they are still being hand made with primitive technology. However, any cracks can easily be repaired by sticking a patch of rubber over the crack with vulcanizing cement and re-vulcanizing the foot, in much the same way as one repairs a puncture in a bicycle tube.

Modifications for Syme's and partial foot amputations

After seeing some of these feet in use in the villages, many amputees requested identical feet. Some of them had Syme's amputation and even though the original design was not meant to cater for their needs, their insistence led to modifications which have been very successful for Syme's stump (Sethi, 1971) (Fig. 14). This would form the subject of another communication.

Fig. 14. Jaipur Syme's prosthesis.

Discussion

Even though the present study was undertaken with certain limited objectives to meet the specific needs of Indian amputees, with their peculiar cultural and functional requirements, the footpiece so evolved has design features which make it suitable for use anywhere. Because of the preoccupation of the prosthetic profession with several exciting developments in the field of socket design, modular systems, knee mechanisms and the availability of new raw materials, the problem of the footpiece has been somewhat neglected. There seems to be a fairly widespread dissatisfaction with the conventional designs and there is definite scope for fresh ideas in this field.

There is little doubt that SACH feet do not stand up to rough use in vigorous outdoor activities. The material used in SACH feet is not durable enough. The use of a vulcanized hard rubber enclosure, reinforced with cord lining, provides a really strong, durable and waterproof enclosure which can withstand more rough handling than any other material. Even if the external shape of a SACH foot is retained, reinforcement with vulcanized rubber or some suitable substitute can enormously strengthen these feet.

The idea of using a foot and ankle assembly which can provide a universal freedom of movement appears to be very desirable. It is not for nothing that nature has evolved the complex joint mechanism in the ankle, subtaloid and midtarsal region. The ability of the foot to adapt to uneven ground is not only kind to the foot itself, but it also protects the more proximal segments of the limb by dampening the ground reactions. This protective role of the joints of the foot in saving the knee and hip from excessive ground reactions has probably not received the attention it deserves. This is presumably because it would take a long time for a knee joint to reveal excessive wear if the ankle and foot were stiff. In an amputee, however, it is the stump which becomes vulnerable to ground reactions and adverse effects are more readily observed. For the comfort of the stump, it is not only accurate fitting of sockets and correct alignment which are necessary but the provision of a universal joint in the foot assembly is equally important; this has been repeatedly proved in this study. The mobility of the footpiece has allowed us to employ many poorly made sockets and imperfect alignments without any adverse effects on the stump.

From time to time, this need had been recognised and designs have been put forward to allow more freedom of movement (Fulford and Hall, 1968).

It is felt that, in general, metallic joints are unsuitable for this purpose. They require a high degree of engineering precision in manufacture, are bulky and heavy and raise problems of lubrication; they also need to be sealed from the environment, especially in wet conditions. Repairs would involve replacing the entire unit which necessarily would be expensive and such repairs cannot be undertaken everywhere.

Many designs have, therefore, relied on rubber for providing mobility (Murphy, 1960). Probably one of the most applauded designs is the Griesinger foot, which is more versatile but the accuracy with which this needs to be made and the quality of the rubber ring would seem to be critical and require a perfection of manufacture which would not be available everywhere. It has not been possible so far to obtain a Griesinger foot to compare its performance characteristics with the Jaipur foot design.

As compared to the foregoing attempts, the design of the joint mechanism in the Jaipur foot has a basic simplicity which is attractive. It is very easy to fabricate: the large size of the sponge rubber block gives it a very substantial range of movement. This is enhanced by the presence of layers in the sponge rubber block which can slide on each other. The enclosure of this unit in a shell of hard rubber provides virtual immunity from breakdowns. Prolonged and extensive field trials under the most adverse conditions have proved the basic sturdiness of this joint.

The forefoot wooden block represents the rigid section of the foot. This provides a lever arm for take-off which gives it a greater mechanical advantage than the relatively short keel of a SACH foot. Because of the presence of the large sponge rubber joint and the rubber toes, it is unnecessary to provide any toe-break and so the full advantage of this lever arm can be exploited. The idea of replacing the single forefoot block with separate metal links which could simulate metatarsals has been discussed but this has so far not been tried. The complexity of such a design and the fear of making the footpiece heavy has acted as a damper to this idea. It is possible, however, that in barefoot walking this device could increase adaptability of the forefoot.

The external skin made of vulcanized rubber not only lends strength to the foot but also serves to modulate the range of mobility. The final range of movement is thus a resultant of the intrinsic mobility of the sponge rubber block and the restraining effect of the external skin. It will be recalled that earlier attempts were hampered by the stiffness of the hard rubber which had to be reduced in thickness. What appeared originally as a drawback has now been harnessed to control the mobility and by increasing or decreasing the thickness of the hard rubber in front of or behind the ankle, one can get any desirable degree of suppleness in the foot. No other existing design is known which has made use of such a control mechanism.

The value of a large area of support provided by the plantar surface has not received any attention by the limb designers so far. This is surprising because this is also an important anatomical feature and makes the amputee feel more secure. This may prove to be particularly useful for the elderly amputees in the West who may find balancing much easier. It may be stressed that a broad flat plantar surface is directly linked with the provision of mobility in the foot mechanism; a stiff ankle would demand a rockered sole to allow a smooth heel to toe action. The area of support in a rockered sole is a relatively small one and consequently the amputee requires some time to learn to balance himself on it. It is also possible that a large area of plantar surface may result in a more effective sensory feedback to the stump. Although this seems plausible no means were available of testing this hypothesis.

The gait with these feet is very natural. Farmers are able to walk on uneven ground with remarkable ease.

The cosmetic features of the footpiece naturally assume importance in all countries where closed shoes are not ordinarily worn. This is perhaps true of most of the warm countries in the Asian, African and South American continents. It is obvious that a very large proportion of the amputee population of the world would require this feature. The social and cultural background also cannot be ignored. Natrajan (1971), in Madras, recognised this need and has tried to reshape a SACH foot to make it resemble a normal foot by carving toes, modifying the heel contour and painting the exterior to match the skin colour. Lest the "Natrajan Foot" be confused with the "Jaipur Foot", it must be made clear that he has not made any alteration in the basic design of a SACH foot and the footpiece is made of sponge rubber. It cannot withstand the rough exposure during the outdoor activities of an Indian peasant. It does not match the strength and durability of the "Jaipur Foot" nor does it have the range of mobility present in the latter.

There is considerable scope for improvement in the "Jaipur Foot". It should be realized that this work was carried out with the help of local craftsmen with primitive facilities, supervised by orthopaedic surgeons with no formal background in prosthetics.

It is felt that even the Western amputee would appreciate a more natural looking artificial foot. There is no reason why a really life-like foot which is light and more durable cannot be produced with the help of the advanced technology in the West. It is envisaged that the entire range of foot sizes in different shades of colour could be produced on an assembly line basis so that they could be taken "off the rack" to suit any amputee.

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