FOOTWEAR IN LEPROSY

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Papers by PRICE in 1960, ANDERSON 1961, ROSS 1961, outlined the pathogenesis, natural history and treatment of plantar ulcers. The importance of mechanical factors in provoking plantar ulcers is stressed and PRICE describes a shoe to overcome certain of them. This paper offers an outline of the mechanical forces thought to be involved, a review of certain efforts to forestall them; a description of footwear now prescribed at the Schieffelin Leprosy Research Sanatorium, and Christian Medical College Hospital, Vellore, with some cautions to be observed and some suggestions for further developemnts.

Mechanical Factors in Plantar Ulceration

Plantar ulceration occurs on walking anaesthetic feet. Enforced rest, either in bed or a plaster cast produces healing in the very great majority of cases. Since the anaesthesia is permanent certain factors involved in the walking process would appear to be the provoking cause, because their removal or diminution permits healing. KELLY in 1958, when discussing the neurotrophic ulcers of diabetes mellitus states, "The distribution of ulcers indicates a mechanical factor". The work of PRICE in Nigeria supports this. It is difficult to differentiate between these factors at the various stages of the walking cycle, but provided it is borne in mind that they interplay with each other, the following stresses can be discerned.

Weight

The area of plantar skin in contact with the ground during walking is shown by a wet footprint. NAPIER (1957) points out that prints differ between walking and standing. We are concerned with the walking print, where the area beneath the metatarso-phalangeal joint of the big toe comes in contact with the ground (Diag. 1). It is seen that the inner longitudinal arch bears no weight, the heel, outer border, metatarsal heads and toe pulps successively transmitting the strain. Examination of the weight bearing foot through a sheet of plate glass reveals that the area of the foot transmitting weight is flattened and blanched. For the moment, the skin is ischaemic. This might be of significance if the foot was static for a long period but this is very seldom the case.

In the walking foot, momentary ischaemia of the plantar skin alternates with blood flow. For this reason necrosis of the skin is probably of little significance as a cause of ulceration. As scar tissue is formed in the plantar tissues however, as a result of ulceration, the viability of the remaining healthy tissues is endangered. Not only has the amount of the blood in the tissues been reduced but hard scar tissue concentrates pressure on adjacent structures. A result of this is that even the normal amount of weight applied to the foot during walking or standing, now becomes a dangerous factor in causing re-ulceration.

To meet this contingency it has seemed logical to utilise the skin of the inner arch as a weight bearing surface and so to reduce the proportion born elsewhere.

Impact

In the normal foot, during walking, the heel hits the ground first. This is sometimes referred to as "Heel strike". In the undamaged foot a soft resilient fibro-fatty pad is interposed between the calcaneum and the skin. The shock of heel strike is absorbed by compression and spreading of the pad. This is also easily seen by observation through plate glass. The metatarsal heads and the skin beneath them are protected from each other in a similar way. Impact stress in the forefoot occurs mainly during running and jumping, dancing, and in ascending and descending steps and slopes. In instances of muscle imbalance this pattern of impact being applied primarily to areas designed to meet it is disarranged. When the peroneal muscles are paralysed the unopposed pull of any remaining invertors causes the lateral border of the foot to strike the ground. The ulcer that develops beneath the base of the fifth metatarsal is the result, since there is no provision for absorbing impact in that area.

Ulceration of the plantar tissues, whether deep and unseen or more superficial and perceptible, results in the formation of scar tissue. Each such injury leaves less resilient tissue to counter even normal impact stresses. Therefore, in shoes designed to prevent re-ulceration a substitute pad must be provided to compensate for the loss of normal tissue. Preliminary experimental evidence indicates that peak walking pressures can be very markedly reduced by a soft insole in a leather shoe.

Shear and Thrust

When weight is transmitted through the metatarsal heads during the "take off" phase of walking, the tissues beneath are subjected to complex forces. As the heel rises, the metatarso-phalangeal joints are extended exposing the metatarsal heads which roll upon the tissues beneath. Apart from pressure there will be shear stresses as body weight and muscular effort force the metatarsal bones backwards on the plantar tissue which are held in firm contact with the ground. The range of movement of the metatarsal heads in relation to the ground is often 40 degrees, while the plantar tissues permit $\frac{1}{2}$–$\frac{3}{4}$ cm. to and from movement of the foot skeleton without slipping. Many feet also exhibit a medial shift of the heel as it rises. This causes a twist between tissues and skeleton at the forefoot. These are normal phenomena.

The development of scar tissue within the $\frac{1}{4}$ in. thickness of the fibro-fatty pad is calamitous since it must materially reduce the gliding properties of the tissue. The metatarsal heads now roll over the tissue which has lost its resistance to shear strains and which is therefore stretched and irritated at every step.

Pressure and shear strains in the immediate region of the metatarsal heads increase in severity as the metatarso-phalangeal joints extend. By keeping these joints in a neutral position at all stages of walking the stresses can be markedly reduced.

Trauma

A variety of forces are grouped under this heading. The work of PRICE in Nigeria demonstrated that the great majority of ulcers start from within the foot. Those caused by direct damage to the skin form only a small minority. Certain causes will be familiar to all who examine large numbers of anaesthetic feet. Thorns or nails may pierce the skin. Burns may result from touching hot coals or walking long distances on scorching tarmac or concrete roads, while poorly fitting and badly designed shoes may cause shoe bites and abrasions. Pain is the greatest boon in preventing damage and its loss can only be overcome by constant and careful watchfulness.

The significance of each of these factors has been demonstrated by often removing only three and seeing the fourth cause re-ulceration. There is a further factor that is only imperfectly understood. What is the initial cause of the first ulcer? Granting the anaesthesia, it has yet to be demonstrated what initiates the development of the first scar tissue. It may be a sudden overstrain—an accenuation of one of the forces mentioned. It may be that there is faulty innervation of the plantar blood vessels which renders the foot susceptible to very minor stresses. Possibly the anaesthetic foot strikes the ground with greater than average force to compensate for a loss of proprioceptive reflexes, but this has yet to be convincingly demonstrated. Be that as it may, elimination or diminution of the mechanical factors outlined has been of great value in preventing re-ulceration in a large number of cases. In this connection it is exceedingly difficult to bring forward figures to prove the effectiveness of this or that kind of shoe in this country. For it is not customary to wear shoes within the house and it has been clearly shown to members of these units that *even ten minutes' walking without protective footwear is sufficient to cause* *re-ulceration in a healed but severely damaged foot.* Experiments are now in progress however, which will show the comparative effectiveness of one kind of shoe versus another in reducing peak walking pressures on plantar tissues. This is being done with the help of pressure-sensitive discs. It is quite another thing however to ensure that the most effective shoes are worn constantly by those who need them. This will only be achieved as propaganda, education and practical proof combine their forces.

It is now postulated that the following points must be borne in mind when designing the ideal shoe for anaesthetic feet.

1. The fullest possible distribution of weight over the plantar surface of the foot.

2. The provision of a soft resilient insole or walking surface.

3. A rigid sole and rocker mechanism which renders movement at the metatarso-phalangeal joints unnecessary.

4. A soft, well-fitted upper.

Review of recent experimental shoe designs

In 1956 ROBERTSON described a method of moulding leather to the soles of individual feet in an attempt to distribute weight widely. The value of this when very carefully done was soon established. It was slow and time-consuming however and a very slight over-accentuation of the inner arch could result in a new pressure ulcer. Between 1958 and 1960 some 150 pairs of shoes were made at Schieffelin Leprosy Research Sanatorium using a modification of the technique of ROBERTSON.

Parallel with this work similar shoes with the addition of sponge rubber insoles or inserts were made. The concept of compensating for lost soft tissues was obvious to us but the results were not always very satisfactory. It became clear that this was in part due to the sponge rubber that we were using which was never designed for the heavy pressure and abrasive wear that was placed upon it. Even the firmest grade was easily compressed fully by the weight of the average man. A full insole lasted for only about three months and the cost of the rubber and the leather covering to protect it was a major item in the total cost of the shoe. With the introduction of microcellular rubber the situation changed remarkably. The Bata Shoe Co. made several grades of this rubber for our experiments and working down through higher numbers and harder grades of rubbers we decided that the resilience offered by the grade of "15 degrees Shore" best met out needs. The anti-abrasive qualities of this rubber when well made are excellent. It is easy to cut and work, can be sewn and stuck, buffed on a machine and very few insoles have had to be renewed in the past 18 months. With the help of the Madnas Rubber Factory a small unit to manufacture this special grade has been set up in the Schieffelin Leprosy Research Sanatorium. Before microcellular rubber became available experiments were also conducted using rubber latex. BRAND had employed this as an outer covering incorporating a plastic insole on a visit to Kano, Nigeria in 1956, and in Vellore had also made moulded insoles with latex and cork dust. In 1959 he described a boot made with latex and rubber dust. This gave a very soft walking surface but experiments were stopped because of the technical difficulty of retaining the rigid member within the latex covering. Our interest in latex has been renewed recently as a means of making water-proof walking casts.

Earlier attempts at obtaining rigidity employed a wooden sole similar to the Chinese clog and considerable work was done with Alkathene, an ICI thermoplastic, a polyethylene derivative. This necessitated the making of a plaster cast and a solid plaster or cement positive on which the hot alkathene sheet was moulded. A steel strip was riveted beneath to give added rigidity and a rocker added to facilitate walking. This shoe met the requirements of rigidity and a moulded weight bearing surface. It also had the advantage of providing lateral stability and support to the heel. But it was clumsy in appearance, heavy, and if the plastic came in contact with the skin abrasive sores were very likely to develop. Attempts were then made to render the ROBERTSON type shoe rigid. Some 60 pairs were made with a horse-shoe shaped piece of 8 SWG spring steel wire incorporated beneath the leather mould. The wire fitted into a second piece of soling leather so that it did not form a ridge in the mould. A car tyre undersole and a rubber or leather rocker was added. This proved fairly satisfactory for the first six months of wear but the steel gradually began to work loose within the sole with a resulting loss of rigidity. Very occasionally the steel snapped when used in an exceptionally long shoe. A wooden undersole was used thereafter and this proved more satisfactory and is the method still used.

Some shoes have been made using metatarsal bars. When these are properly applied they transpose the weight from the metatarsal heads to the region just behind. They do not prevent shear. Large numbers have been used at the Christian Medical College and the National Research Institute, Chingleput. CURRIER (1959) reports their use at Carville. That they have a value is not doubted but rigidity is much to be preferred from a medical standpoint.

Footwear now in use

Two main patterns of footwear are now used extensively among the out-patients of the Schieffelin Sanatorium. They are the microcellular chappal with car tyre under sole and rigid soled shoes. The rubber chappal, or sandal (Diag. 2), is prescribed for all patients who exhibit anaesthesia of the foot, who show superficial cracks at the sides of the heels and for feet which have one very small mobile ulcer scar with no pain.

Ideally in the latter instance rigid soled shoes should be worn, but generally it seems wiser to provide a sandal that is socially more acceptable and is likely to be worn constantly rather than a rigid shoe which may, to the patient, appear unnecessarily cumbersome. The chappal consists of a ½ in. (1.27 cm.) layer of 15–20 degree microcellular rubber stitched to a car tyre undersole. One leather strap passes across the forefoot from first to fifth metatarsal head. A second lies just anterior to the ankle and a third, with a buckle on the lateral side passes around the back of the heel. The straps are inserted between the two soles and stitched. A stock of these sandals is kept and fitting and adjustments take only a few minutes. At present the cost of such a pair is about Rs. 5.00 (seven shillings and sixpence sterling, or rather more than 1 dollar, U.S.). The car tyre undersole is an essential part of the chappal which is not found on the commercial variety. It serves three functions. It stiffens the sole and to some small extent hinders metatarsophalangeal extension. It saves the microcellular sole from excessive wear from cuts and slashes on its underside. But most important it prevents thorns from piercing the soft rubber and entering the foot. This last is a very real danger under the conditions most of these sandals are worn.

The rigid soled shoe is recommended for all cases of healed plantar ulceration other than those suitable for a rubber chappal. These shoes should never be used as a means of achieving healing of ulceration for which the plaster cast is both designed and effective. Their purpose is to prevent recurrence. They are prepared while the plaster cast is being worn and are fitted as soon as the cast is removed before any walking is permitted after removal of the cast.

The shoes are made on wooden lasts. This is necessary in order to provide a covered heel, without which the effect of the rigid sole is largely lost, and which also prevents much lateral movement with a consequent increase in stability. We have used the ordinary commercial shoe lasts with certain adaptations rather than have special lasts made which discourage other institutions from taking up the work. The first adaptation is to cover the sides and top of the last with soling leather about ⅛ in. (0.32 cm.) thick. Thus the width of the last is increased in relation to its length (Diag. 3). This has been found necessary since most of the feet we cater for have been free of shoes during formative years and are therefore broader than the foot accustomed to shoes from an early age. The second alteration is to increase the depth of the last by ½ in. (1.27 cm.) by adding layers of leather to the undersurface on the heel, outer border and forefoot only. This is to allow the ½ in. (1.27 cm.) microcellular rubber insole to be inserted after removal of the last. Because the area of the inner longitudinal arch is packed to a lesser extent the inner arch of the

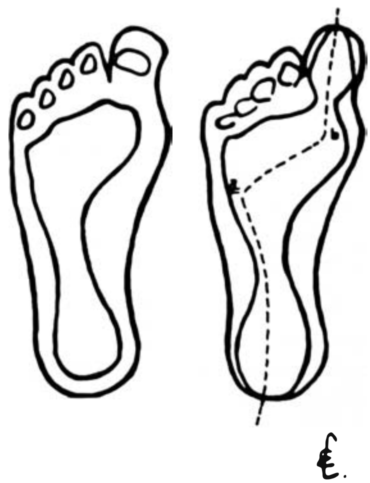


Diagram 1. The difference between a standing print (a) and a walking print (b). The dotted line shows the weight passing from heel to great toe.

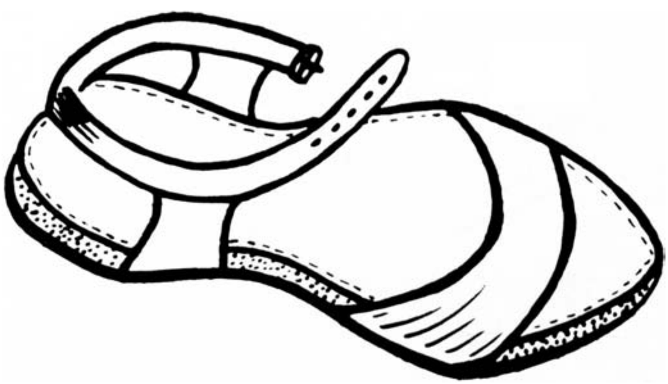


Diagram 2. The rubber sandal. A sole of car tyre is stitched to a ½ inch layer of 15-20 degree shore microcellular rubber.

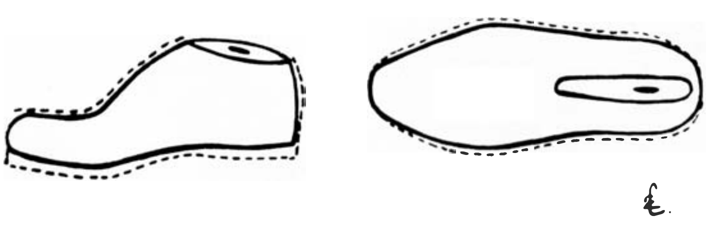


Diagram 3. To allow for an increase in width and depth of the finished shoe, the wooden lasts are packed with leather or cardboard. The instep is packed less than the heel and forefoot.

finished shoe is raised in relation to the rest of the sole (Diag. 4). This makes the longitudinal arch of the foot bear a proportion of the body weight. A complete set of lasts is treated in this way and thenceforth needs only small adjustments to compensate for such minor deformities as are met with, such as claw toes and enlarged joints. Gross deformities at once fall into a group needing the attention of a skilled surgical shoe maker.

The upper of the shoe is cut, lined and sewn to the welt of the last in the usual way. If this phrase is reminiscent of the directions in a cookery book it is because, as with cooking, this work is best done by someone with basic "know-how". A detailed dissertation on the elements of shoe making is not intended. The diagram illustrates the type of upper we employ. The reason for interwoven straps is that they permit the fit of the shoe to be easily checked and adjustments made on the spot. With the enclosed shoe the cobbler has to depend on the report of the wearer and when sensation is lost and shoes are in any case an unfamiliar item of attire such dependence is most

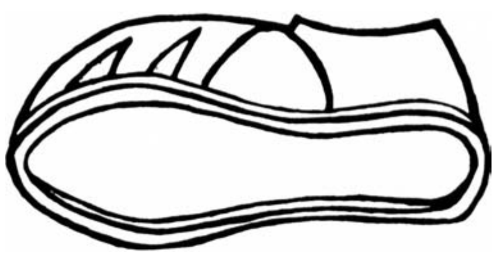
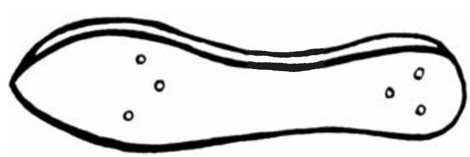


Diagram 4a. Shoe is on the last and the strip of leather has been stuck to the welt making a bed for 4b the 5-plywood insert marked with drill holes.



4c. The wooden rocker and heel 1¼ ins. high.

unwise. It does have the disadvantage that toes sometimes catch between the straps when putting the shoes on but this momentary annoyance is outweighed by the advantage of always being able to make a rapid check of correct fit. The straps are quite acceptable in this area of India.

When the upper has been sewn to the welt the accentuated arch of the insole is supported by several layers of leather stuck together. A second welt is then stuck to the first with paste or rubber solution. A strip of good soling leather $\frac{1}{2}$ in. (1.27 cm.) wide and long enough to reach around the whole shoe is used (Diag. 4a). This extra strip must be the same thickness as the wooden stiffener for which we use 5-ply wood. In this way a bed is formed. The last is now removed from the shoe, and the stiffener placed in position. Screw holes are drilled from the inside of the shoe through the heel seat, the stiffener and into the wooden heel. Also through the area behind the metatarsal heads, the stiffener and into the rocker. The ends of the holes within the shoe are countersunk so that the heads of the screw lie flush with the leather insole. Three screws each for the heel and rocker usually suffice. The heel and rocker are now screwed in place. The forepart of the stiffener is then covered by sewing car tyre to the welt. The rocker and heel have car tyre tacked to them with $\frac{1}{2}$ in. (1.27 cm.) nails. When the microcellular insole is slipped into the shoe it is ready to be fitted (Diag. 5).

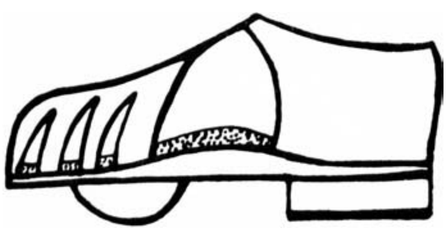
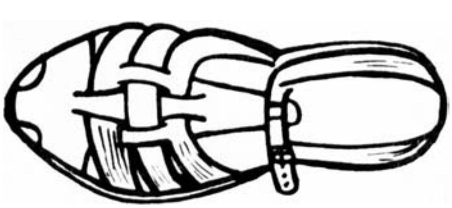


Diagram 5a. The rigid soled shoe complete with rubber insole and raised medial arch.

5b. Showing the interwoven straps of upper.



The best position for the rocker has not yet been proven. We have tended to keep it as far back as possible without the empty shoe tilting forward. This is in order that the metatarsal heads should not be directly over the rocking line. But the further back the rocker is placed, the higher it must be to maintain the normal walking angle of 30–40 degrees (Diag. 6). If this is not maintained, the front of the shoe will tap the ground at each step. Another factor controlling the height of the rocker is the length of stride. A person who walks with a small step can manage with a much lower rocker than a person with a long stride. It must be remembered, too, that the metatarsal joints are the normal line at which to bend and the nearer the centre of the rocker is to these joints the more natural the gait and the less the strain placed on the heel buckle strap. The shape and dimensions of the rockers and heels that we use are shown in Diagram 4. These, with the stiffeners may be made in quantity.

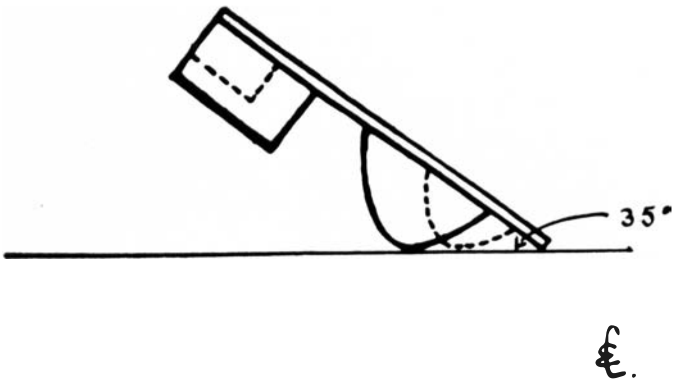


Diagram 6. The walking angle depends on the length of stride. Maintenance of the angle in a rigid sole shoe depends on the height and position of the rocker.

The finished shoe is shown in Diagram 5. If wedges are required for mild and mobile foot imbalance they may be added without difficulty. The shoes are effective in preventing re-ulceration when properly made and used, are durable, but not, it must be admitted, very elegant. This was a drawback at first, but when their value had been demonstrated by a few patients the demand rose and has remained. Recently, however, PRICE and RIORDAN have demonstrated at the Schieffelin Leprosy Research Sanatorium shoes similar to a pattern worn by foundry workers in England. Trials with this type are now in progress.

A small number of sandals with rigid soles have been made. The microcellular sole is raised on the inside to support the longitudinal arch and is sewn to a leather sole, beneath which is fixed a stiffener of either steel or wood. Because these are not made on a last and therefore have not a covered heel, the play permitted by the single heel strap allows some movement at the metatarsal-phalangeal joints. Only a low rocker is therefore required. While we have been examining the whole principle of rigidity we have wished to avoid such a hybrid as this on any large scale, but a number of patients have done well with them and prefer them to the full rigid soled shoe and it may be that this type will be developed when current experiments have shown the degree of rigidity necessary to achieve a marked reduction in shear and thrust. KELLY, in 1958 states that the majority of the cases in his study on neurotrophic ulcers in diabetes mellitus probably owed their origin to poorly fitting shoes in conjunction with anaesthesia. Quite certainly, anaesthetic feet require greater care in fitting than those of the person with skin sensation. It is relevant here therefore to mention some of the hazards associated with shoes and sandals. Friction sores are high on the list of dangers and while it may appear that most patients cannot financially afford socks it may be that medically they cannot afford to be without them. Common sense indicates that shoes should be "worn in" during the first week of wear. There is a practical difficulty however, since few patients will face the need to purchase new shoes before the first pair has completely worn out. Again, the straps on a new shoe are likely to fit very firmly to allow for the inevitable stretching of the leather within the first few days of wear and firmness must not be confused with over-tightness. Occasionally if the sides of the heel covering are made too high, the skin beneath the malleoli will be rubbed. This is easily altered. Claw toes and enlarged joints must be given sufficient room. The mud pyramid sometimes makes its appearances on well used shoes. This term is used to describe the ridge or cone of caked dirt which is liable to form beneath an ulcer which reopens and exudes pus or serum. The dirt, caked hard with this excellent dried gum fits into the ulcer and concentrates pressure in the exact place that it will do most damage. Cleaning the shoes is the clear remedy. Careless and slipshod repairs are major hazards. The thonging sometimes used to bind soles together in country sandals can form pressure points.

But perhaps pride of place should be given to that cobblers' time saver—the nail. The Indian village chappal is a remarkable example and is often a veritable storehouse of iron held together with leather.

Shoes are only second in importance to finding the initial cause of plantar ulceration, and overcoming it. Until such time as that can be done they must take a very important place. There is a great room for improvement in style and lightness over those described. A means of making waterproof shoes for use in field work must be developed, and an adhesive to obviate much of the stitching should not be too difficult to discover. The great number of people in need of footwear, and their economic situation have to be borne in mind and cost and ease of manufacture have to be taken into consideration.

Summary

The importance of preventing recurrence of ulceration is stated. The mechanical factors of weight, impact, thrust and shear are outlined in relation to ulceration and means suggested of overcoming them. Certain traumatic causes of ulceration are given. Two types of shoe are described, the sandal to prevent initial ulceration and a rigid soled shoe to prevent recurrence. Hazards of shoe wearing are given and suggestions for future advances made.

Acknowledgements

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