STUDIES ON PLANTAR ULCERS IN LEPROSY

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1 General

Introduction

Plantar ulcers are a major obstacle to the present-day rehabilitation of leprosy patients. We know that they occur in anaesthetic feet, and have an obvious relation to weight-bearing, and a possible relation to trauma, but do not know the full story of their causation nor why they are so chronic, nor why they relapse so easily. There must be some other factors.

We use the term "plantar ulcer" instead of the usual names "perforating", "trophic", or "pressure ulcer", because these latter terms are not always truly descriptive. In using the term "plantar ulcer" we exclude ulcers due to infection, trauma, or fungus infection (as in clefts of the toes) and define it as a chronic ulceration of the anaesthetic sole of the foot, situated in well-defined areas overlying a bony prominence, resistant to local or systemic therapy, and characterised by a marked tendency to recurrence.

Survey of Plantar Ulcers

We undertook two surveys of plantar ulcers in the leprosaria of Eastern Nigeria. In the first survey we examined the plantar ulcers found in about 2,400 patients under leprosy treatment, and noted the position and character of the ulcer. In the second survey we treated and observed closely the ulcers in 100 patients. In addition and at the same time, we examined weekly every patient without ulcers in one leprosarium, in order to detect the earliest signs of impending plantar ulceration: this has turned out to be very valuable as a preventive measure.

Our initial investigation suggested a new approach to the study of plantar ulcers under the following heads; their distribution in leprosy; the mechanics of the foot in relation to them; their cause and the cause of their chronicity; their natural history; their early detection and prevention and treatment; and their complications.

The Distribution of Plantar Ulcers

From the literature we find that there is a general recognition that they occur in certain common sites, e.g., under the metatarsal heads, but there has been no study which relates the distribution to stresses undergone by the feet in standing and walking. We studied this matter in 2,395 patients in four leprosaria, and found 561 plantar ulcers representing 11.7 ulcers per 100 feet. There was a higher incidence in feet of males than females (12.7 as to 9.5), but no difference between right and left feet. There was a difference in incidence in different leprosaria, varying between 6 and 16 per 100 feet. This is partly related to the predominant type of leprosy in the area, and partly to the method of dealing with ulcer patients; some leprosaria admit ulcer patients from outlying clinics more readily. Part of the difference is related to the actual method of treatment adopted for ulcers. The leprosarium with the least incidence has used treatment by plaster casts for the past few years.

It was found that the sites of the ulcers tended to be the clearly defined areas overlying a bony prominence. Thus 71 % of the ulcers are under the forefoot, in sites which closely follow the operation of dynamic pressures on the walking foot. The heel bears only 12.5 % of ulcers and therefore is the least common area for plantar ulcers. The middle of the outer border of the foot bears 16.5%. It will be noted that the heel bears more standing pressure, yet is the least common area. Ulcers involving the mid metatarsal area have been spread over more than the one metatarsal head and make it difficult to decide which was the primary lesion.

The photograph in Fig. 1 illustrates the typical sites of plantar ulcers in leprosy. This case is unusual in showing four of the commonest sites of plantar ulcers, namely under the first and second metatarsal head, under the tubercle on the base of the fifth metatarsal and on the heel.

Feet which have been deformed by previous gross infection or from surgical intervention on the metatarsal bones may show ulcers in other sites, according to the deformity.

The limitation of ulcers to certain special sites makes it possible to advise a system of recording which relates the ulcer to the underlying bony prominence and uses the initial letters of the bone. Thus MH_1—MH_5 would mean an ulcer over the metatarsal head as numbered; mid-MH would mean mid-metatarsal; mid-lat. would mean an ulcer over the base of the fifth metatarsal; PPH means the plantar ulcer seen quite often over the proximal phalangeal head of the first toe. Except for the second toe, the other toes rarely have it.

Ulcers at the tips of the toes are frequently multiple in any given case and can be considered as a single ulcer spread over the tips of more than one toe. With this reservation, we find that of 100 plantar ulcers, 61 are single, with one on each of 61 feet; 30 are double, with 2 on each of 15 feet; 9 are triple, with 3 on each of 3 feet. We also find that of 100 patients with plantar ulcers, 58 have a single ulcer on 1 foot; 22 have two ulcers on 1 foot only; 4 have 3 ulcers on 1 foot only; 15 have 1 ulcer on each foot; 1 has a single ulcer on 1 foot and 2 ulcers on the other.

Excluding 2 tip ulcers, the greatest number of ulcers was 7, with 4 on 1 foot and 3 on the other.

In the few cases of multiple ulcers there were all possible combinations of sites. The commonest combination was that of heel and mid-metatarsal ulceration on the same foot.

Discussion and Summary

The most striking feature of the distribution of plantar ulcers is the predominance in the forefeet, where 70% of ulcers occur. In the forefoot itself most ulcers are on the medial side. The heel is the least common of the usual sites. If one relates pressure diagrams of the standing and the walking foot to the distribution of plantar ulcers, it is obvious that the distribution of pressures on the walking foot is much the more important. The distribution of ulcers and all dynamic pressures on the walking foot correspond closely, except for the occurence of mid-lateral ulceration, and a slightly lateral displacement in the forefoot of the position of maximum incidence of ulcers. These two differences may be related to the weakness of the pronators of the foot which is a feature of the damaged foot in leprosy. A review of the mechanics of the walking foot appears in the next section of this study.

A brief summary of our observations follows:

1. Plantar ulcers were observed in 11 of every 100 feet of patients under treatment for leprosy in Eastern Nigeria.
2. Seven of every ten plantar ulcers occur in the forefoot.
3. The commonest single site is under the second metatarsal head.
4. The commonest area is that of the big toe and associated metatarsal pad.
5. The heel is the least common of the usual areas of ulceration.
6. The plantar ulcer is commonly a single ulcer on one foot of a patient, but one in six ulcer patients have one on each foot, and one in five have two ulcers on one foot. Triple ulcers are uncommon and quadruple ulcers rare.
7. The typical plantar ulcer occurs in clearly defined areas in the following order of frequency:
    i. under the second metatarsal head.
    ii. under the first metatarsal head.
    iii. under the lateral metatarsal heads.
    iv. under the tubercle on the base of the fifth metatarsal.
    v. at the heel.
8. Ulcers of similar type were observed under the head of the proximal phalanx of the big toe, and on the tips of the toes.
9. Ulcers are commonly associated with, or preceded by, callosities.

II The Mechanics of the Foot in Relation to Plantar Ulcers

In the first part of this study we reached the point of emphasising

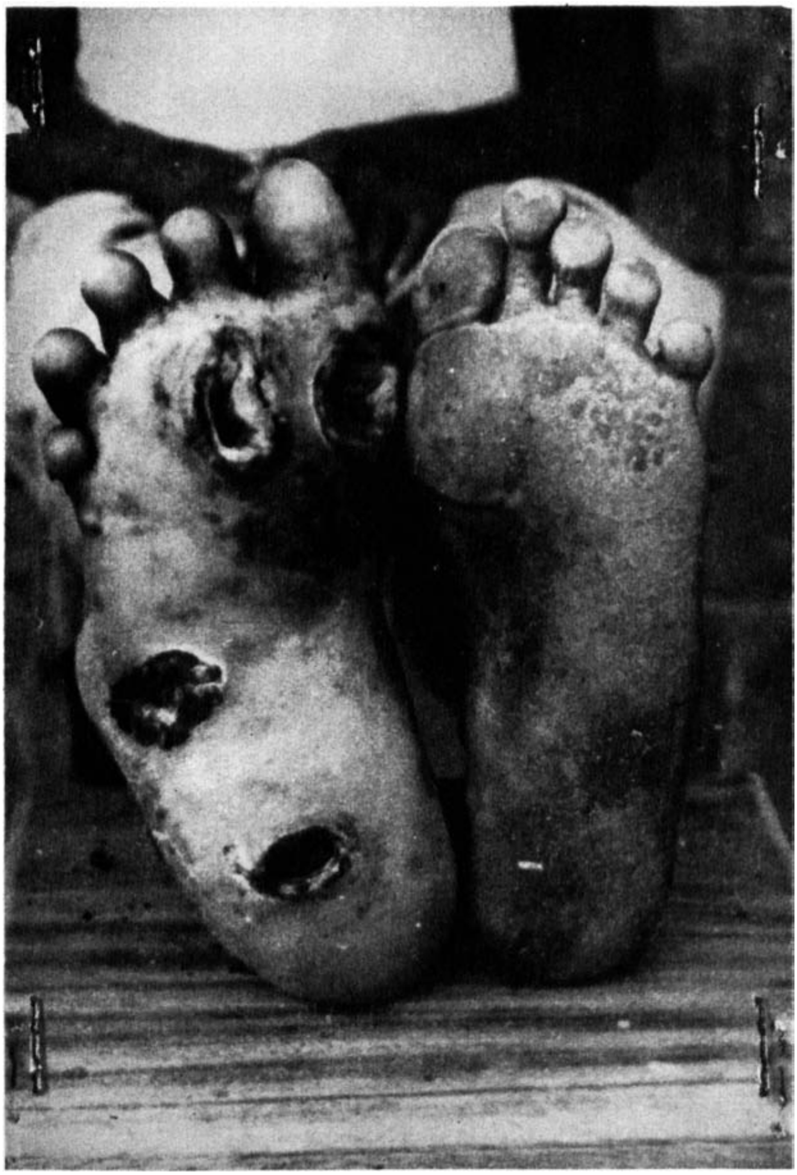


Fig. 1 The typical sites of Plantar Ulceration in Leprosy.

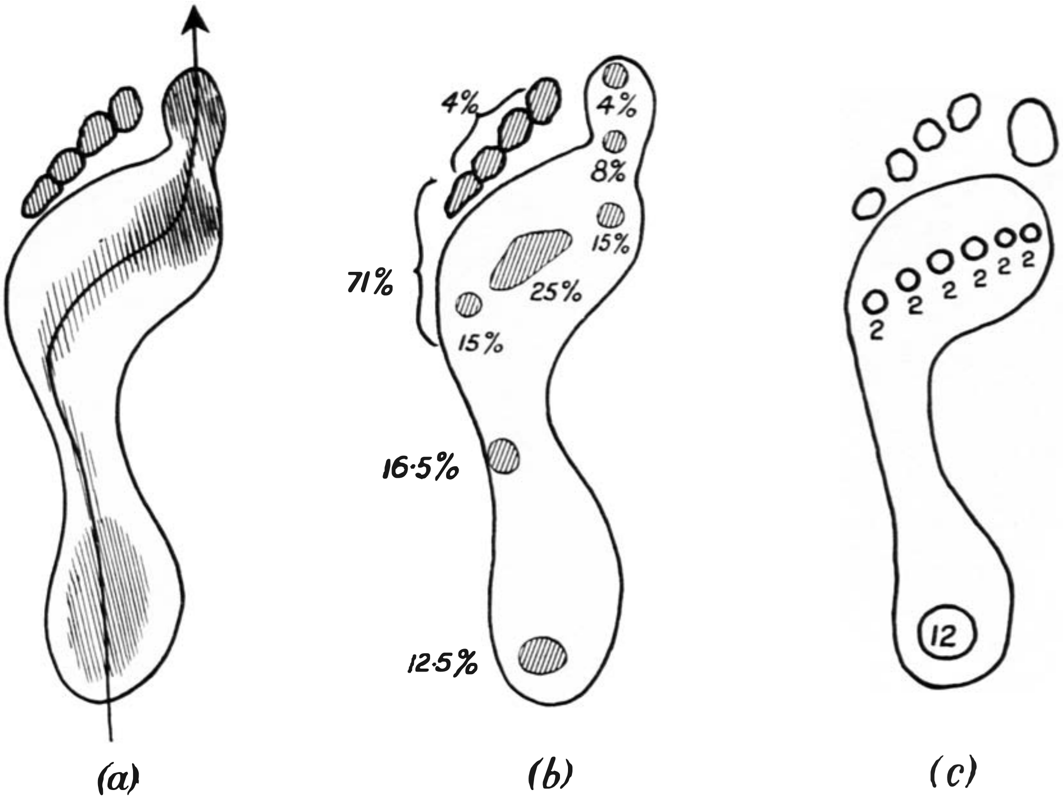


FIG. 2

(a) The footprint of the walking sole. (after Morton)
The shading represents the degree of walking pressures. Note that these pressures pass across the sole in succession from heel to toe-tips following the direction of the arrow, and that the toe-tips play a definite part in the sequence.

(b) The distribution of plantar ulcers in leprosy.
Note that the distribution is far closer to those of the walking pressures than to the standing pressures. The tendency for maximal pressures to be displaced laterally, and the particular ulcer at the base of the 5th metatarsal, are related to the pronator weakness characteristic of the neuropathic foot of leprosy.

(c) The footprint of the standing sole. (after Morton)
The figures represent kilogram pressures on each area for a man of total weight 48 kg—24 on each foot. These pressures exist simultaneously on all areas so long as the patient stands on the foot. Note that the toes play no part in supporting the standing pressure.

the importance of walking pressures, and now wish to proceed to a study of the mechanism of walking as concerns the sole of the foot, especially the region of the metatarsal pads of the big toe.

The walking cycle involves almost the whole of the skeletal musculature and most of the joints. It depends on the integrity of sensory circuits concerned with balance and the avoidance of slipping on the ground. This mechanism was first studied in detail by Carlet 90 years ago, but he lacked the technical facilities for a full understanding. Recent workers (Morton 1935) have greatly increased our knowledge and this has been applied to clinical problems by Lake (1952) and others. Recent techniques, notably of high-speed cine-photography, have thrown more light on the details (Barnett, 1956) and it can be said that the mechanics of walking are fairly well understood.

The walking cycle, with special reference to the sole of the foot is examined as follows:

1. The walking "roll" and sole pressures.
2. The "angle of gait".
3. Sole dorsiflexion during the walking roll.
4. The function of the big toe in walking.
5. The intrinsic musculature of the foot in walking.
6. The role of sole sensation.
7. Types of gait.

1. *The Walking "Roll" and Sole Pressures*

Each step of walking involves a roll of the body across the sole of each foot in succession from heel to toe tips. The line of the roll begins at the point of heel-contact, and passes rapidly round the under-surface of the heel, up along the lateral border of the sole to the region of the head of the fifth metatarsal bone; thence it passes across the metatarsal heads to the first, and finally turns forward along the big toe to its tip (Fig. 2a). The speed at which this roll takes place depends on the rate of walking, but at a brisk pace each roll is completed in about $\frac{3}{4}$ of a second.

The pressure associated with this cycle also pass rapidly across the sole, and follow in sequence so that no portion of the sole is compressed for longer than half a second. The pressure is moderate at the heel, then falls rapidly as it passes along the lateral border of the foot; turning medially across the sole, the pressure builds up to a maximum over the sesamoid bones of the first metatarsal head, and continues forward at a high level till the final push-off in which all the toe tips co-operate.

These pressures have been measured and may reach as much as 20 kg (45 lbs.) more than half the body-weight, which is the standing pressure on one foot. The remainder of the body-weight is meanwhile transferred by the momentum of the body.

It will be noted that, on *standing*, the pressures on each sole are simultaneous all over the pressure-bearing area of the sole (Fig. 2c). This pressure is distributed so that half the amount is on the heel and half on the forefoot (Morton 1935). The forefoot pressure is itself equally distributed between the four lateral metatarsal heads. It will be seen that each head or sesamoid bears one-sixth of the pressure on the forefoot, which is one-twelfth of the total pressure on the sole—or one-twentyfourth of the total body-weight.

For a man of 50 kg (115 lbs.) this is about 2 kg ($4\frac{1}{2}$ lbs.).

The heel, which is the least common area for plantar ulcers, bears six times the standing pressure of any bony prominence in the forefoot. The importance of the walking pressures as opposed to the standing pressures is reflected in the relative strength of the metatarsals. The first, which bears only twice the standing weight of each of the other digits, has much more than twice their bulk and strength.

The distribution of plantar ulcers in leprosy is reproduced in Fig. 2b, so that the relation to walking pressures may be evident. The slight differences that exist can be related to the pronator weakness which is characteristic of the neuropathic foot of leprosy.

2. *The "angle of gait"*

Most people out-toe slightly in walking, and the degree of external rotation relative to the direction of walking is known as the angle of gait. The effects of this angle are described in detail by Napier (1957). In the study of plantar ulcers, it should be noted that an alteration of the angle of gait modifies the site of maximal sole-pressure and the function of the big toe in the push-off. A wide angle transfers the pressures medially, while a narrow or negative angle displaces the pressures and the push-off towards the lateral toes.

This difference must be kept in mind in noting the distribution of plantar ulcers among patients of different areas, and between the sexes. In the survey described, it was noted that among the women, in particular, the position of maximal plantar ulceration tended to vary from region to region; and it was observed that the carrying of heavy loads, which often included babies, was associated with a tendency to walk with a wide base and some in-toeing, or lessening of the angle of gait.

3. *Sole-dorsiflexion during the walking roll*

The roll of the walking step occurs, not across a rigid sole, but across a flexible structure which dorsiflexes so as to present a type of rocker. This is illustrated diagrammatically in Fig. 3, which is compiled from data given in the series of cinephotographic exposures at high speed reproduced by Lake (1952) from Elmslie's work.

The importance of this mechanism is emphasised by observing the artificial foot which gives the best imitation of the natural gait. This is illustrated in Fig. 3, where the three points round which the

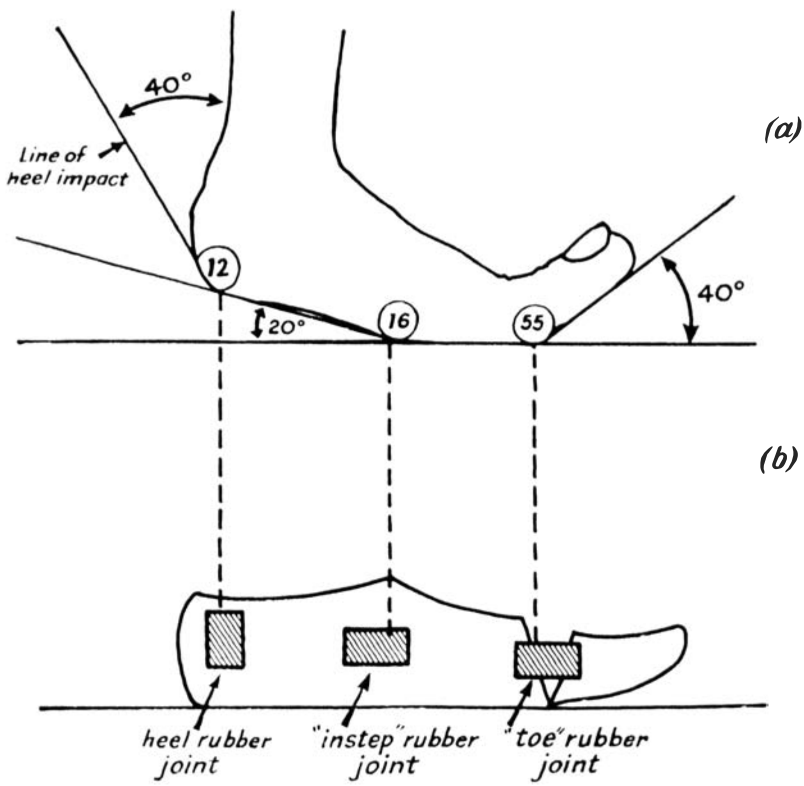


FIG. 3

The points of Rotation-pressure on the sole

(*a*) *A composite diagram summarising the three points of rotation-pressure and indicating, in degrees, the amount of rotation occurring in the walking "roll" during a brisk step. The foot is shown at the middle of the cycle, and the big toe is dorsiflexed to the extent to which the metatarsals dorsiflex on the big toe at the final push-off. The degree of heel rotation on heel-contact is also indicated. The encircled figures indicate the percentage of plantar ulcers occurring at each site.* (*b*) *A tracing of a wooden artificial foot, showing the rubber joints normally placed to obtain a suitable gait; these are at the points of rotation under discussion.*

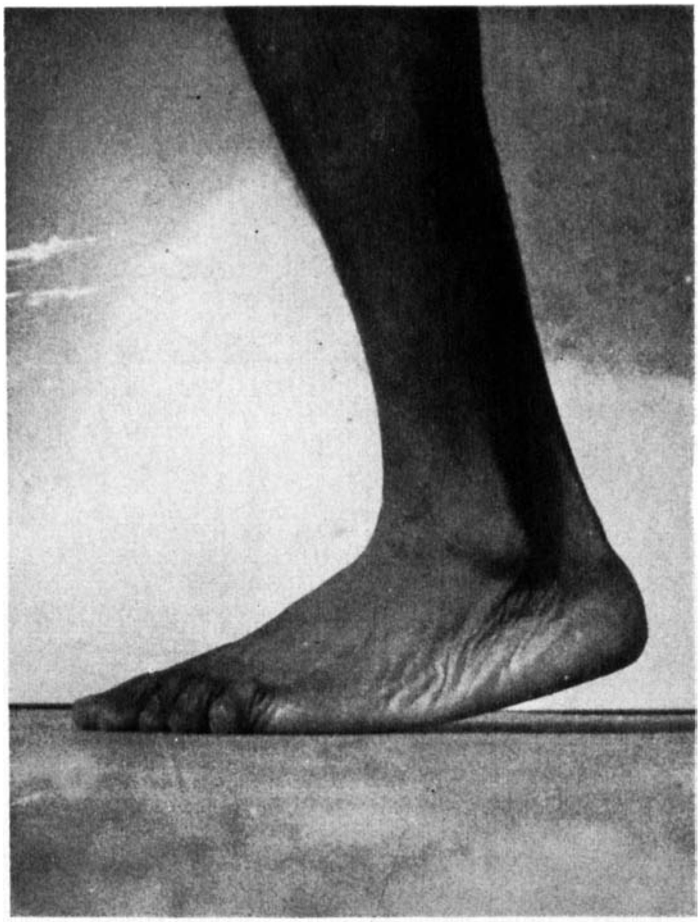
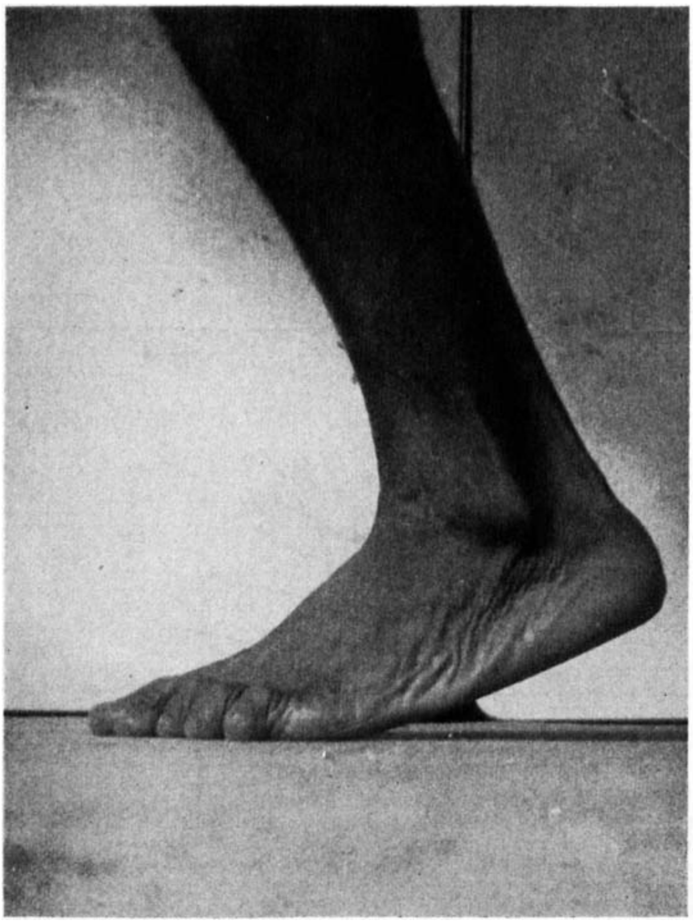


FIG. 4

The Walking Foot

Photographs taken during walking at 1/500th of a second.

(*a*) *Dorsiflexion at the mid-lateral joint. Dorsiflexion up to 20° takes place in the region of the base of the 5th metatarsal during the walking roll. A sesamoid not infrequently protects the tissue from friction damage. In failure of the protective mechanism, plantar ulcer is not uncommon (16.5%) at this point.*



(*b*) *Dorsiflexion at the metatarso-phalangeal joints. Dorsiflexion at the M-P joints reaches as much as 45° and the walking pressures are at their maximum. The metatarsal pads are the commonest sites of plantar ulcers.*

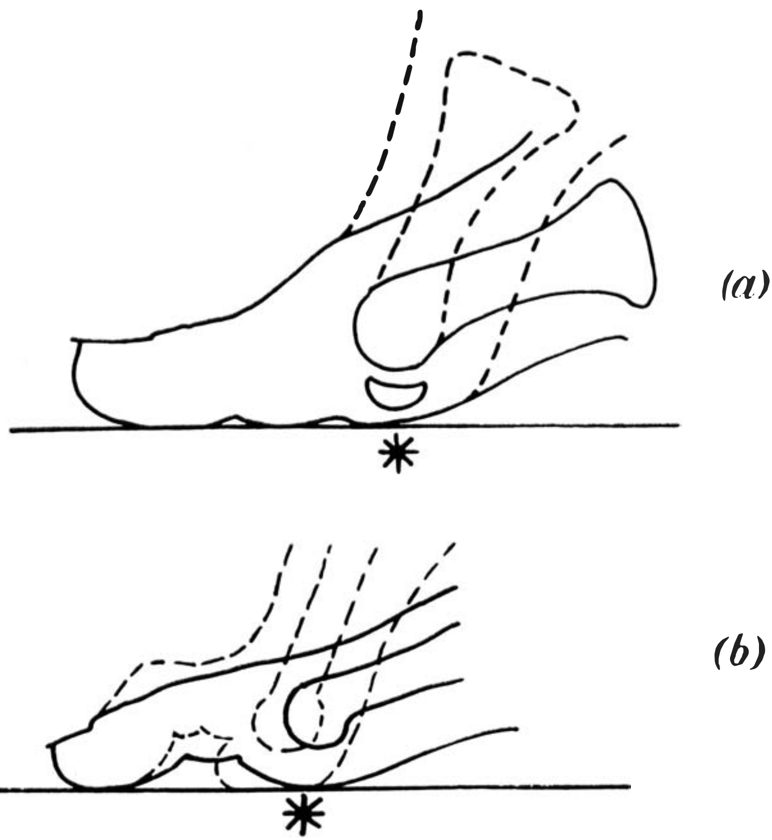


FIG. 5

Method of absorption of friction-pressures during dorsiflexion of metatarsals with each step

(*a*) *The big toe. Tracings of X-rays of beginning and end of metatarsal rise. Here damage to tissues is avoided by rotation of the metatarsal head in situ, on an underlying cartilage buffer (the sesamoids). The big toe does not move.*

(*b*) *The lateral toes.*

In these cases, the damage is avoided by a rolling-forward of the metatarsal head, with the underlying pad of tissues, much as a garden roller does on a lawn. The corresponding toe slowly brakes the roll to a standstill at the moment of push-off, by firm contact at its tip.

The asterisk indicates the point of maximum incidence of sole-ulcers in leprosy.

roll occurs are cushioned by three rubber "springs". These are named, by limb-makers, the heel, instep and toe rubbers, though in fact the "toe" rubber is placed at the site of the metatarso-phalangeal joints. A "foot" without these rubbers is very clumsy in action.

The degree of rotation and the percentage of plantar ulcers occurring at each site of rotation are indicated in the diagram.

Mid-foot rotation occurs between the cubo-calcaneal and cubo-metatarsal joints, but the latter is better constructed than the former for dorsiflexion, and is the commoner of the two sites for plantar ulcers.

The foot in action is shown in Figure 4, taken by high-speed photography during the act of walking.

Rotation, under pressure, of the degree that occurs in walking must be associated with considerable friction in areas of the sole where rotations take place. It should be noted that these are the site of 91% of plantar ulcers, if the tips of the toes are included.

There must evidently be some method by which these frictions are controlled or dissipated so that they do not damage normal tissues on the numerous occasions that they take place every day. That there are two distinct mechanisms for avoiding damage in the forefoot is evident by the observation of the sesamoids under the first metatarsal head, and their absence under the others. The occasional presence of a sesamoid under the mid-lateral joint is significant in this connection.

Radiographs of the bony and soft tissues during the actual step clarify these mechanisms as follows:

(*i*) *Rotation mechanisms at the first metatarsal head* (*Fig.* 5*a*)

The first metatarsal head rotates in *situ* during the walking step, somewhat as the femur does on the tibial plateau. It is prevented from slipping forward by the big toe, which remains rigid and in full contact with the ground until the end of the metatarsal rise.

The plantar skin of this area does not move during this time, but it can be seen that any point on the under-surface of the metatarsal head rotates backward through an angle of 40° or more. The considerable friction thus engendered is absorbed, as at the knee, by a cartilage buffer, cartilage being the only tissue in the body capable of absorbing, without damage, repeated pressure-frictions.

The sesamoids present a cartilage surface to that of the overlying head, and so absorb the friction that would otherwise damage unprotected tissues.

It can be seen that tissue-protection is afforded at the first metatarso-phalangeal joint (*a*) by the stability of the sesamoids, which are kept in contact with the head during the motion, and (*b*) by the rigidity of the big toe. If either or both of these are compromised, tissue-protection is in jeopardy.

(ii) Rotation mechanism at the lateral metatarsal heads (Fig. 5b)

At the lateral metatarsal heads, a different mechanism is involved. The pressures are a good deal less and a simpler protection suffices. It will be seen that the metatarsal head, as it rises, rolls forward with the underlying pad of tissues much as a garden-roller rolls forward across the lawn.

The stresses are gradually reduced to zero by the action of the corresponding toe, which remains in contact with the ground only at its tip, and which produces a gradual braking effect by slowly and actively yielding to the advancing forefoot. The downward pressure on the ground exerted by the tip of the toe reflects this action; it increases steadily to a maximum at the final moment of push-off.

As in the case of the big toe, it can be seen that a toe that failed to stop the forward roll of the metatarsal bone and pad exposes the tissues to damage.

4. *The Function of the Big Toe in Walking*

The big toe is a common site of plantar ulcer, especially at its base, and the role of the big toe in walking is important. Attention has been drawn to the fact that the walking roll, as it passes across the sole of the foot, ends by turning forward along the big toe for the final push-off. The thrust is larger the faster the gait, and in such circumstances as walking up-hill or in sandy soil.

The pressure on the big toe at push-off is little less than that occuring elsewhere in the foot. When the loss of stability is taken into account (following weakness of the flexor hallucis brevis and other intrinsics of the foot), it is not surprising that plantar ulcers occur here for similar reasons to those responsible for ulcers on the sole proper. In fact, the big toe can be considered as a miniature sole from the point of view of walking.

In cases where the big toe is lost, or fails to function, or where the patient habitually in-toes, the second toe can partially take over big toe function. In such cases in leprosy, the plantar lesions typical of the big toe are seen on the second toe.

5. *The Intrinsic Musculature of the Foot in Walking*

While the intrinsic musculature of the hand is largely concerned with the grasp and other finer movements of the hand, that of the foot is mainly concerned with the act of walking—though barefooted people can and do pick up objects from the ground with their toes.

The importance of stability of the toes in protecting the sole from damage during the friction-pressures of walking has been stressed. It should be recalled that the muscle controlling flexion of the proximal inter-phalangeal joints of the lateral toes is an intrinsic muscle in the foot, while in the case of the hand it is a forearm muscle, and so largely spared in leprosy.

This means that the foot is more crippled than the hand by weakness of its intrinsic musculature.

6. *The Role of Plantar Sensation*

The tendency to slip during the walking step is considerable if ground friction is inadequate, as a walk on ice will confirm. The friction necessary to prevent slipping is therefore important to the walking mechanism and depends on the character of the ground. The actual friction-force on the sole is increased either by an increase in the roughness of the ground, or by an increase in the proportion of total body-weight put on the foot as the step is taken. If the ground is smooth or unstable, extra weight must be thrown on to the stepping foot, as the gait of the sailor testifies.

Sensation of the sole is an important factor in informing the brain of the amount of weight that must be transferred to the sole to prevent a fall.

In the absence of this information, the only solution is to put excessive weight on each step, so as to be sure that friction is adequate to prevent a slip. Without sensory control, the brain can only add weight blindly and so this is always much greater than would suffice if sensation were normal. Thus lack of plantar sensation automatically involves increased pressure on the sole during walking.

7. *Types of Gait*

The types of gait have been adequately described by Lake (1952) and are significant in the treatment of the damaged foot in leprosy. Lake describes a "springy" gait, seen in its most obvious form in the walking race, and the "rigid" gait, which is the traditional gait of the soldier wearing thick-soled rigid boots. Either gait can be employed at will, but individuals vary in their use of them.

Although the rigid gait appears ungainly, it is found to give maximum protection to the sole of the foot and is used by the armies of the world, where foot-protection is particularly desirable. It will be recalled that wooden clogs—which induce a rigid gait—are standard footwear in many parts of the world. Advantage is taken of the rigid gait in the development of the treatment and prophylaxis of sole-ulcers described in a later chapter.

Summary

1. Attention is drawn to the high incidence of plantar ulcers in leprosy on the parts of the foot where walking pressures are maximal, and the importance of the walking mechanism is stressed.

2. Details of this mechanism are discussed in relation to the occurrence of plantar ulcers.

Acknowledgements

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