Foot pressures in leprosy

WFW-REPORT 96.008

M.A. Kiel

Foot pressures in leprosy

stageverslag

Guidance:
Prof. dr. K.M. Patil
Biomedical Engineering Division
Indian Institute of Technology
Madras, 600-036, India

Dr. Ir. L.H. Braak
Department of Mechanical Engineering
Eindhoven University of Technology
Eindhoven, The Netherlands

January 1995

FOOT PRESSURES IN LEPROSY

by

M. A. KIEL

under the guidance of

Prof. Dr. K.M. PATIL

DEPARTMENT OF APPLICED MECHANICS
INDIAN INSTITUTE OF TECHNOLOGY
MADRAS - 600 036

NOVEMBER 1994

Abstract

In this study, a barograph is being used for on-line measurements of plantar pressures under both feet. The analysis of pressures may be a useful help to prevent paralysis of leprotic feet by early diagnosis and treatment. It may also be useful in the management of patients by aiding in the correct design of orthopaedic footwear and appliances. The leprotic patients were divided into different categories, according to the kind of problems and the stage of leprosy the patient is in. The feet of the patient have been divided into 10 areas, and two indices were used to characterise the plantar pressure distribution. The first of these indices represent the area under the pressure-time graph normalized for the weight of the person (pressure-time index), and the second one represents the time of contact of the area in respect to the time of contact of the entire foot (contact-ratio index). We found that significant difference in the contact-ratio index between the categories of patients occurred in the heel and the metatarsal heads respectively. This index can thus be used as a quick indication of possible foot problems in leprosy patients. The effect of operation of drop-foot has also been investigated. The distribution of plantar pressures can be an qualitative measurement for the success of the operation. The most useful application of this technique in the future is to patients who are in the early stages of the disease, who appear to be at high risk for ulcer development and yet exhibit no lesions at the time of study. Once the regions of abnormal pressure distribution have been recognised, a variety of treatment regimes could be instituted to prevent breakdown of the foot. Pressure distribution measurement could also play a significant role in the evaluation of the success of the various treatments as surgical correction of dropfoot.

Contents

Chapter 1 : Introduction

Leprosy is still a widespread disease in India as well as many other countries in the world. The most of the troubles of the foot in leprosy is not due directly to leprosy at all, but it is due to the loss of sensation which results from leprosy. Almost all the troubles are a result of the patients inability to feel pain, and thus unable to protect himself from the dangers that he cannot feel.

Biomechanics is a scientific discipline which studies biological systems such as the human body, by the methods of mechanical engineering. Since gait is a mechanical process which is performed by a biological system, the methods of Biomechanics are ideally suited to its investigation.

Owing to its wide variety of functions, the foot has been considered to be one of the most dynamic structures within the body. It provides physical contact with the environment, especially during gait when it must constantly adjust to the varying loads placed upon it during the initiation and termination of ground contact. Any changes in the structure and/or flexibility of the foot will modify its function, resulting in changes in the way in which the foot is used during gait. The most important factors contributing to satisfactory function in the foot are its shape, the distribution of pressure over the sole and the adequacy of sensibility. Leprosy patients often develop ulceration on the soles of their feet, which influences the function of the foot in a negative way. A number of studies showed that pressure is the cause of these ulcers [Stokes et al., 1975, Betts et al., 1978]. So foot pressure measurement can be an important aid in the early diagnosis of foot problems. It is possible that occurrence of ulcers on the feet of at least some leprosy patients is preventable if foot care is considered an important part of the total patient care during the early stages of the disease.

In this study, an attempt has been made to predict the stage of leprosy a patient is in, and to recognise early stages of possible foot problems. Also studied is the effect of foot-drop correction operations. After corrective operations sometimes too much pull has been placed on the inner side of the foot. In such cases the lateral border of the foot comes down heavily on the ground and the base of the fifth metatarsal bone forms a projection against the ground. This often results in ulcers on the lateral border of the foot. The pressure-measurement can here be used as an early indicator for the problems.

Chapter 2 : Anatomy of the foot

2.1 Introduction

The surfaces of the foot are referred to as plantar and dorsal surfaces, and its borders are referred to as medial or tibial and lateral or fibular. The big toe is the hallux; the little toe is the digitus minimus. The toes are numbered beginning with the big toe. The skeleton of the foot is beautifully designed to give a maximum of strength for a minimum of bulk and the trabeculae of bone are placed in exactly the right relationship to the forces they have to bear. In addition to good design, the foot has the benefit of sensation. Sensory nerves keep the brain constantly informed about the stresses and strains on the bones and the ligaments and tendons of the foot.

2.2 Skeleton of the foot

The foot is a very complicated structure, which is thought as being in three parts:

1 The hind foot, which consists of two bones, one on top of the other.
2 The midfoot, which consists of five bones, packed closely together.
3 The forefoot, which consists of the five metatarsals and the toes.

In the foot, there are seven tarsal bones (fig 2.1). Of these the talus alone enters into the articulation with the bones of the leg. The talus is the upper of the two bones in the hindfoot. It rests upon the calcaneus. The calcaneus lies below the talus. The posterior end of the calcaneus receives all the weight on the heel. Between the talus and the calcaneus is the subtalar joint, and between the anterior ends of both bones and the

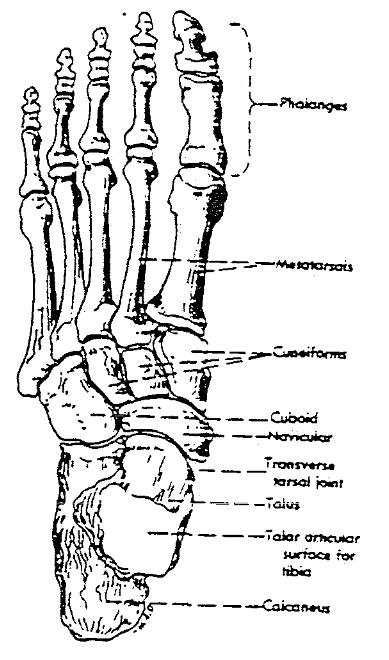

Figure 2.1: *The bones of the ankle and foot; dorsal view.*

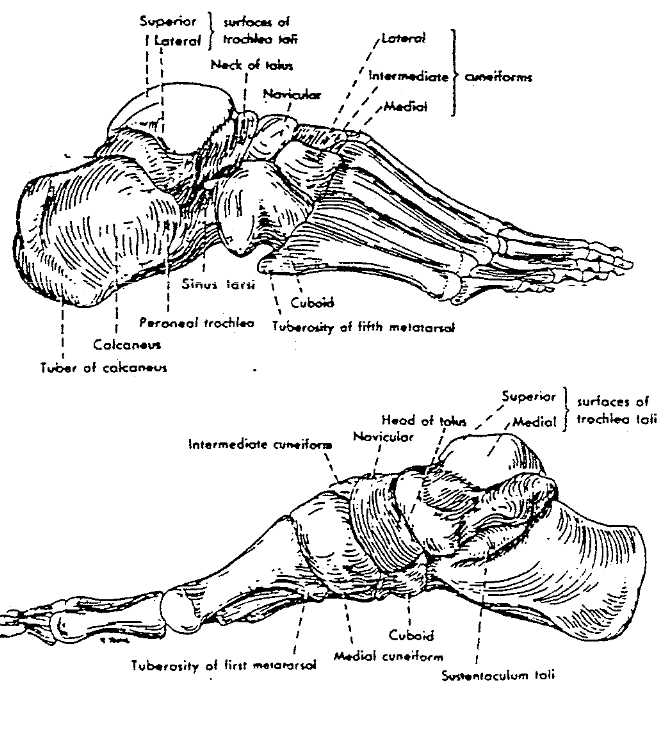

Figure 2.2: *Bones of the foot from the lateral and medial sides.*

more distal tarsals is the transverse tarsal joint. The anterior surface of the calcaneus articulates with the most inferior and lateral of the midfoot bones: the cuboid. The midfoot consists of five bones: the navicular, the cuboid and the three cuneiform bones. The cuboid and the cuneiforms articulate with the metatarsals. These in turn articulate with the proximal phalanges of the toes. Because of the arch of the foot, the weight in standing is normally transmitted to the ground only through the posterior end of the calcaneus and the distal ends of the metatarsals. The phalanges are the bones of the toes; there are two in the big toe and three in each of the other toes. The toes, especially the big toe (hallux), participate in the thrust in walking, when the weight is shifted forward onto the ball of the foot. The plantar aponeurosis is essentially a strong, superficially placed ligament that extends in the middle part of the foot from the calcaneus to the toes and that plays an important part in supporting the arch of the foot.

2.3 Movements of the foot

The ankle joint (or talocrural joint) is a hinge like joint with a mediolateral axis. It has globally one degree of freedom, the movements are almost entirely limited to flexion and extension. The sole of the foot is usually referred to as the plantar surface, and the "top" of the foot is the dorsum. By use of these terms, the movement at the ankle can be described. The rising upon the toes is plantar flexion of the foot, and standing upon the heels is called dorsiflexion of the foot. Dorsiflexion is due to the actions of all the muscles crossing the front of the ankle. The tibialis anterior is the most important muscle involved in this action. When the tibialis anterior is paralysed, the other muscles contact more strongly to dorsiflex the foot, and the extensor hallucis longus therefore dorsiflexes the big toe. Dorsiflexion with paralysis of the tibialis anterior may be accompanied by eversion of the foot because the peroneus tertius and the extensor digitorum longus may evert more strongly than the extensor hallucis longus inverts. The movement of the foot is not restricted to the talocrural joint, but also occurs among the tarsals. The foot, placed on the ground, can turn over the longitudinal axis. This is a complex movement. The sole of the foot can be turned medial, this movement is called inversion. The movement in the opposite direction, turning the sole of the foot outward is known as eversion. Huson, 1985 has stated that all articulations at the tarsal level are functionally linked, and that the talus, calcaneus, navicular and cuboid bones form a closed kinematic chain, i.e. a constraint mechanism with only one degree of freedom. This means that motion of one will inevitably affect all the others. It is found that turning over the longitudinal axis of the foot is attached to a rotation of the leg. With an inversion, the leg undergoes an exorotation. Similarly, an exorotation of the leg causes an inversion of the foot.

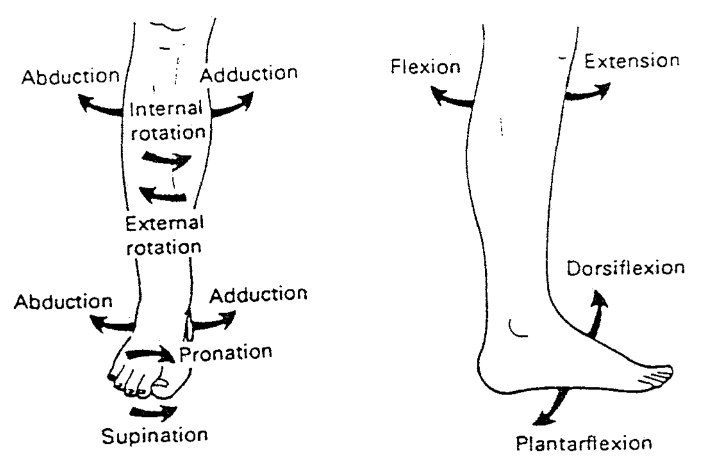

Figure 2.3: *Movements of the leg and the foot.*

Movement Dysfunction

The muscles of the calf are all innervated by the tibial nerve; therefore injuries to this nerve may not only interfere with the "push-off" in walking but make it impossible for the limb to bear weight unless an ankle brace is worn. The centre of weight of the body lies anterior to the ankle joint. Therefore, the activity of plantar flexors is necessary to prevent the foot from going into dorsiflexion, with a resultant forward shift of the weight of the body. The anterolateral muscles of the leg, being all innervated by branches of the peroneal nerve, may be paralysed by injury to this nerve. The outstanding symptom of its injury is an inability to dorsiflex the foot, resulting in an so-called foot drop when the lower limb is raised from contact with the ground. In this condition, when one attempts to walk, the foot must be raised far enough from the ground to provide clearance for the toes. Since it is impossible to make the heel strike first, because of the inability to dorsiflex the foot, the foot is simply flopped down. Because the muscles of the leg, rather than those of the foot, move the foot, imbalance among the muscles of the leg can markedly distort the foot. There are numerous grades and directions of distortion, but a general name to cover them all is clubfoot (talipes) [Jenkins, 1991]. It has long been recognised that postnatal fibrosis or paralysis of a muscle will lead to clubfoot of some type, and that in congenital clubfoot some of the muscles are abnormally short. There is still disagreement as to whether the muscle imbalance causes or is caused by malformation of the bones of the foot. There are a number of simple examples of clubfoot. If the triceps surae is spastic or fibrotic, or if its tendo calcaneus is abnormally short, this powerful plantar flexor will hold the foot in a permanently plantar-flexed position, so that the heel bears no weight. If the tibialis anterior is spastic or fibrotic, the foot is held in dorsiflexion and inversion. If the peroneus longus and brevis are spastic, the foot is held in eversion. Correction of clubfoot is largely a matter of correcting the relations of the bones of the foot to each other, and of restoring muscle balance. This can sometimes be done by applying a succession of casts; however, operations to realign the bones and to lengthen or transplant tendons may be necessary. Since all the muscles in the sole of the foot are innervated by the tibial nerve, tibial nerve injury may result in paralysis of them all.

2.4 The ankle and the foot in supporting weight

The centre of gravity of the body passes posterior to the hip joint and anterior to the knee joint, so that the weight borne on the extended limb helps keep these joints extended. Since hyperextension is resisted by ligaments, no sustained muscular effort is required to hold the pelvis, thigh, and leg together as a supporting pillar. The situation is different at the ankle, however, where the centre of gravity passes anterior to the normally dorsiflexed joint, so that the weight of the body tends to dorsiflex it even farther. Thus, even quiet standing requires contraction of the plantar flexors of the foot, a duty that normally falls upon the soleus [Jenkins, 1991]. If there is any difficulty in keeping the balance, as there is in standing upon only one foot practically all the muscles of the leg contract in order to stabilise the inter tarsal and talocrural joints and to prevent any inversion or eversion of the foot. Since all weight is transmitted to the rest of the foot through the talus, the position of this bone on the arch of the foot is important. It is obvious, that an arch that remains normal must be very strongly constructed. This is obtained by a strong bony conformation, which is supported by the plantar ligaments. The plantar ligaments are the primary support of the arch. In quiet standing, the normal foot needs no other support. When additional support is needed, as in standing upon the toes or in walking, the short muscles of the foot become active. The support of the arch, therefore, comes from the plantar ligaments and, when necessary, the plantar muscles, which stretch along the arch like tie rods. The long muscles seem to contribute to the preservation or destruction of the arch only in that they are responsible for keeping the foot properly balanced between eversion and inversion, therefore, for the normal distribution of weight over the arch. If they fail to do this, excess weight is thrown upon either the medial or the lateral side of the arch, and this may be more than the ligaments, even with the aid of the short muscles, can withstand without stretching. Thus, while imbalance of the long muscles may lead to deformation of and pain from a normal arch, strengthening them by exercise cannot be expected to increase the support of the arch [Jenkins, 1991]. Chodera, 1985 found that in a right handed person more pressure is normally put on the left heel and right forefoot and vice versa in the left handed. A normal heel has about one half of the surface area of the forefoot but it carries the same load. Comparing all fore and hind foot areas against each other the specific overload of the segment can be revealed. A chronically overloaded heel with deteriorating padding function of the soft tissues produces a club shaped widening of the otherwise smooth contour of the footprint.

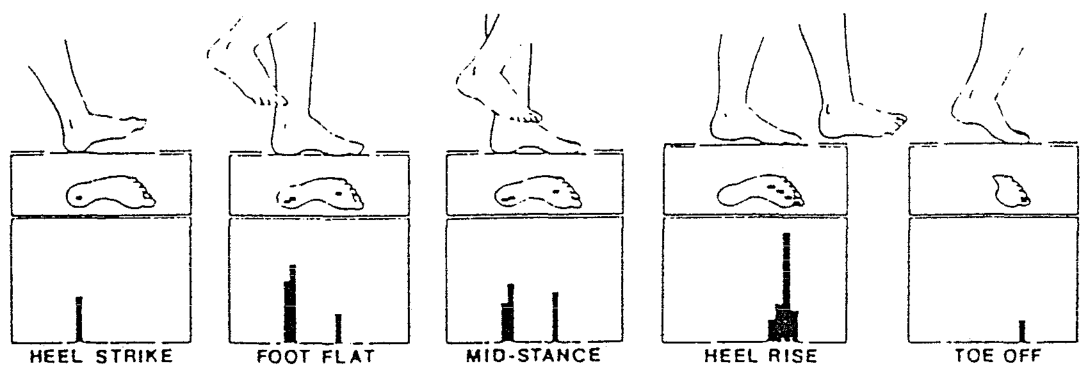

Figure 2.4: Five events during the gait cycle.

2.5 Gait

In order to study abnormal gait, it is first necessary to study normal gait, since this provides the standard against which the gait of a patient can be judged. Normal walking can be defined as `a method of locomotion involving the use of the two legs, alternately, at least one foot being in contact with the ground at all times, to provide both support and propulsion,' [Whittle, 1991]. The gait cycle is defined as the time interval between two successive occurrences of one of the repetitive events of walking. It is decided to start with the heel strike as shown in fig 2.4. Each leg has a swing-phase, when it moves forwards through the air, and a stance phase, when the foot is on the ground, and the body passes over the top of it. The following major events are used to divide the gait cycle into convenient periods for the

stance phase	
1	Heel strike
2	Foot flat
3	Mid-stance
4	Heel rise
swing phase	
5	Push off
6	Mid swing
(1	Heel strike)

purpose of description:
In normal walking the heel strikes the ground first, followed by a rapid loading of the remainder of the foot. The centre of gravity of loading begins in the proximal part of the heel and passes over the medial side of the foot to the second metatarsal head, and ends at the lateral border of the great toe. As the load moves forward and approaches the metatarsal heads, the heel leaves the ground, body weight being borne entirely by the forefoot. Although the highest loads are exerted on the heel, it is the forefoot that is involved for the greater part of foot contact time. The medial side of the forefoot is heavily loaded, with the hallux carrying about twice as much as the metatarsal head. The toes serve mainly as an accessory to the ball of the foot, providing attachment of the long flexor tendons. By differential contraction of these flexors it is possible to adjust the distribution of pressure between points on the ball of the foot [Soames et al.,1985]. Because of the strength of the great toe and the long flexor tendons attached to it, this part of the foot is usually the last to leave the ground, contributing the final touch to the control of movement. Up to 20 percent of body weight acts on the great toe at toe-off, this is counteracted by tension in the flexor tendons, which react with the force on the great toe to produce a resultant force approaching body weight on the first metatarsophalageal joint. While little muscular activity is required during quiet standing, walking requires the co-operation of a number of muscles. The muscles involved in walking

vary according to what the limb is doing. This can be described as consisting of two phases. The stance-phase lasts from heel strike to toe off. The swing-phase lasts from toe off to the next heel strike. The duration of the complete gait cycle is known as the stride time; it is divided into the stance time and the swing time. The swing-phase occupies about one-third of the cycle, the stance-phase two-thirds; thus, when walking, both limbs are simultaneously in the stance phase about a third of the time. Heel strike by the right foot occurs while the left foot is still on the ground, and there is a period of double support between heel contact on the right and toe off on the left. During the swing phase on the left side, only the right foot is on the ground, giving a period of right single support, which ends with heel contact by the left foot. There is then another period of double support, until toe off on the right side. Left single support corresponds to the right swing phase, and the cycle ends with the next heel strike on the right. In each gait cycle, there are thus two periods of double support and two periods of single support. Heel strike is the beginning of the stance phase. It is called `heel strike', since there is often a distinct impact between the heel and the ground, known as the `heel strike transient'. There is considerable variation between individuals as to how much force is applied to the ground at heel strike, some people `gliding' the foot on the ground, and others `digging' it in.

Figure 2.5 shows a trace of the vertical component of the ground reaction force measured from an individual with a marked heel strike. The heel strike transient is fairly short, typically lasting between 10 and 20 ms, and it can only be observed using a measuring equipment with a fast enough response time.

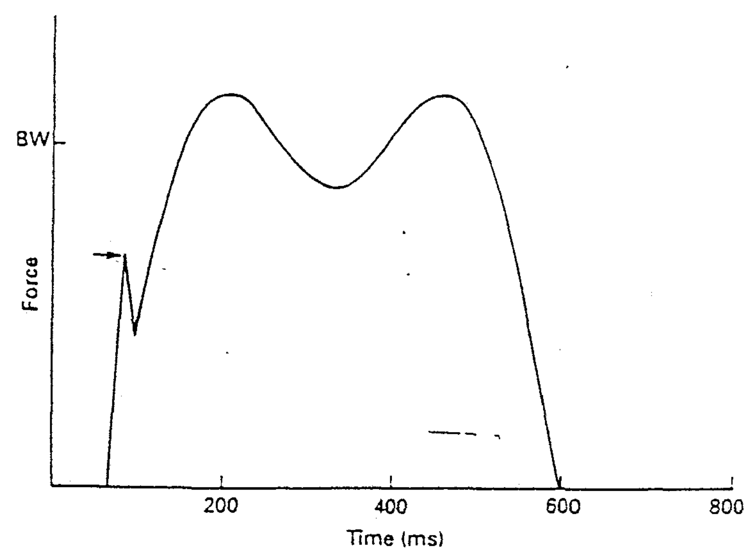

Figure 2.5: *Plot of vertical reaction force against time, showing the heel strike transient. BW= body weight.*

Push-off is normally produced by plantar flexion of the foot. If the triceps surae is paralysed, or if the tendo calcaneus has been severed, it can be accomplished to a lesser extent by the use of the gluteus maximus and the posterior hamstrings to extend the hip. (Initiation of push-off can be entirely passive. As the body leans forward, producing dorsiflexion at the ankle joint, the posterior leg muscles can act primarily to check the forward movement of the body.) The swing phase involves almost simultaneous flexion at the hip and flexion at the knee, followed by dorsiflexion at the ankle. During the first part of the stance phase, until the foot is flat on the ground, the triceps surae contracts in order to control the forward shift of the body over the foot. Passive dorsiflexion of the foot occurs as the body is carried farther forward, and the plantar flexors then contract again to initiate the push-off of the next cycle. The short muscles of the sole of the foot also contract as the weight is shifted onto the ball. During the part of the stance phase that the other foot is clear of the ground, the gluteus medius and minimus (of the supporting limb) contract to prevent undue drooping of the unsupported side of the pelvis.

Chapter 3 : Effects of leprosy

Leprosy patients often develop ulcers on the soles of their feet. These ulcers are most common under the second, third and fourth metatarsal heads. Stokes et al., 1975 found that pressure is the cause of these lesions, since ulcers usually occur at sites of elevated plantar pressure. It is sensory neuropathy, resulting in a reduction of afferent sensory perception, which allows ulceration to occur at sites of high pressure because no pain can be felt by the patient.

The most of the troubles of the foot in leprosy patients is not due directly to leprosy, but it is due the loss of sensation which results from leprosy. Almost all the troubles are a result of the patients inability to feel pain, and thus unable to protect himself from the dangers that he cannot feel.

3.1 The nerves of the feet in leprosy

In tuberculoid leprosy, paralysis may be one of the earliest symptoms. In lepromatous leprosy, it usually comes on more gradually. Thus in lepromatous leprosy it may be possible to prevent paralysis by early diagnosis and treatment. There are two places at which nerves affecting the foot are commonly paralysed:

1. The first is the posterior tibial nerve. The paralysis of this nerve causes loss of sensation of the sole of the foot and paralysis of all the intrinsic muscles of the foot resulting in the "clawing" of the toes and a weakening of the "bowstring" of the arch of the foot. In clawed toes, the tips of the toes get ulcerated. In more severe clawing, the toes get pulled up off the ground, and then the metatarsal heads have to bear extra pressure.
2. The second common site of paralysis is in the peroneal nerve as it winds around the neck of the fibula. (see figure 3.1). Paralysis of the peroneal nerve results in "foot drop" and loss of all extensor powers in the toes, and also paralysis of the peroneal muscles. Thus, the dorsiflexors and the evertors of the foot are paralysed while the plantar flexors and invertors remain normal. At about the same time that sensation is lost from the sole of the foot, the ability of sweating is also lost, so absence of sweating may be used as an index of danger.

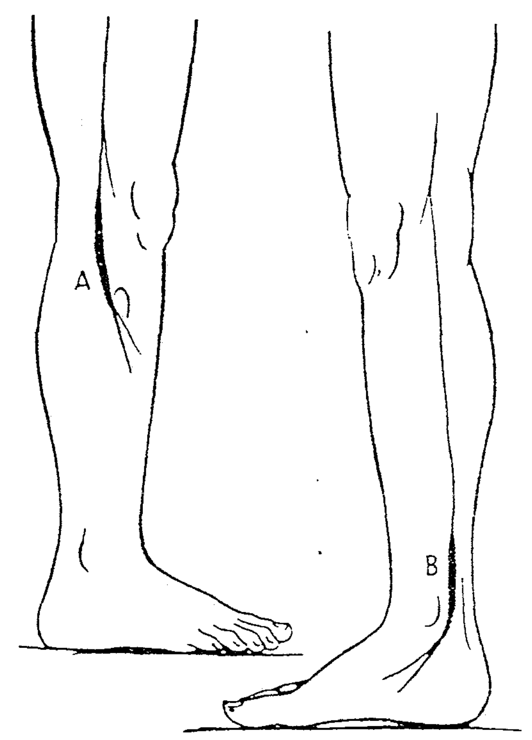

Figure 3.1:
(a) Peroneal nerve ; (b) Posterior tibial nerve.

3.2 Plantar ulceration

The basic cause for plantar ulceration is the loss of sensation. Leprosy patients often develop ulcers on the sole of the foot under the heel and under the metatarsal heads. There are at least four different ways in which insensitive feet are destroyed. These four result from quite different levels of force being applied to the foot, and they destroy the foot in totally different ways. These are the four:

1. A low pressure acting a long time on the foot. It will cause gangrene (necrosis) of the part by lack of blood supply. This is a biological kind of destruction. The pressure is much too low to do direct damage.
2. A very high pressure may cause direct and immediate damage and death of tissue by crushing, tearing or cutting. This is mechanical destruction. Similar immediate damage may be from heat or from corrosive chemicals.
3. A frequent repetition of a moderate amount of pressure. This moderate pressure would not cause pain to a sensitive foot as long as it happened not too many times. If the pressure acts a lot of times, the pain is caused by inflammation that gradually develops and weakens the tissue so that it finally breaks down. This is the most common cause of ulcers on the foot. In a paralysed or deformed foot there is one part of the foot that takes more pressure than another. In peroneal paralysis, the lateral border of the foot often gets too much pressure. In clawed toes, the tips of the toes get ulcerated. In more severe clawing, the toes get pulled up off the ground, and then the metatarsal heads have to take extra pressure because the toes take none.
4. A moderate force acting in the presence of an infection. This results in spreading of the infection and destruction by osteomyelitis and other forms of sepsis.

3.3 Bone damage

The bones of the feet in a leprosy patient may be damaged in three different ways.
Neuropathic and vascular changes can occur in patients with leprosy and can effect the foot in a variety of ways which combine to alter the plantar pressure pattern and cause ulceration. Sensory neuropathy causes loss of both pain and joint position sense; autonomic neuropathy causes a lack of sweating, leading to brittle skin and altered distribution of blood flow; motor neuropathy causes atrophy of the intrinsic muscles of the foot with consequent loss of vascular changes reduce the ability of the tissues to respond to damage or infection and its capacity for repair. These two main factors of neuropathy and vascular changes can occur separately or in combination, and sepsis can occur with either but is most serious in patients with vascular impairment. Quantitative assessment of these risk factors allows prediction of patients liable to develop foot ulcers.

a. <u>Leprosy osteitis.</u>
Invasion of the bones may cause a leprosy inflammation or osteitis. This may weaken the bones so that if the patient walks rather violently at this stage they may collapse. This is not common, because leprosy osteitis only occurs in the severe forms of lepromatous and border-line leprosy and the bones are occasionally affected badly enough to cause a danger of collapse.
b. <u>Sepsis.</u>
Damage from sepsis is extremely common. As plantar ulceration destroys the soft tissues of the foot, There is no tissue that lies between the bone and the outside world, and infection from the road or from the shoe can immediately enter the foot and go direct to the bones, causing osteomyelitis. If the patient goes on walking after the ulcer has formed then the unprotected end of the bone becomes more and more deeply infected, the surface of the bone crumbles away and becomes eroded, the nearby joints become infected and dislocated and destroyed. Thus the infection that begins at the metatarsal heads may, after further walking, infect the tarsal bones, and destroy the arch of the foot.
c. <u>Mechanical strain.</u>
The skeleton of the foot is beautifully designed to give a maximum of strength for a minimum of bulk and the trabeculae of bone are placed in exactly the right relationship to the forces they have to bear. In addition to good design, the foot has the benefit of sensation. Sensory nerves keep the brain constantly informed about the stresses and strains on the bones and the ligaments and tendons of the foot. A special danger in insensitive feet is that very small cracks in a bone and very small tears in a ligament may not be noticed by the patient because they do not hurt. Therefore, he

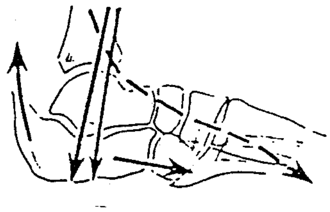

Figure 3.2: Damaged calcaneus results in weakened pull of gastricnemius and thus weakened force of forefoot. The body weight now reaches the ground straight through the front part of the calcaneus.

continues to walk on a damaged bone or joint, and makes the damage worse until the whole bone may be destroyed.

Patterns of disintegration.

Damage may occur in one of the following faces of gait:

1. Heel strike.
The calcaneus may be cracked either from landing heavily on the foot at a time when the bone is decalcified, from sepsis, or from disuse. When the calcaneus becomes fractured or weakened by sepsis the strong calf muscles pull up the back half of the calcaneus and then the weight of the body will be taken through the centre of the foot. This nearly always results in serious ulceration's leading to destruction of the whole foot (see figure 3.2).
2. Mid-stance.
When the foot is flat on the ground, the weight of the body is shared by the heel and the side of the foot, and the front of the foot, therefore no part takes excessive pressure, and severe damage is unlikely. The one exception to this is when the foot is slightly inverted so that the patient tends to walk on the outer border of the foot. This occurs when the peroneal muscles are paralysed, and has sometimes followed operations for foot drop where too much pull has been placed on the inner side of the foot. In all such cases the lateral border of the foot comes down heavily on the ground and the base of the fifth metatarsal bone forms a projection against the ground. An ulcer on the lateral border of the foot opens the way to sepsis to the centre of the arch. This leads to severe septic destruction of the bones in the centre of the foot.
3. Push-off phase.
Sometimes in a partly paralysed foot the muscles and ligaments on the underside of the foot become stretched and the arch tends to flatten and the lever is weakened. If a person takes very a strong thrust on his foot, one of the bones at the centre will crumble and break and the foot then becomes flat and may even bend so that the arch is reversed and the front of the foot becomes unable to accept any thrust at all. When that happens, the centre of the foot takes all the strain and the foot may be destroyed (fig 3.3).

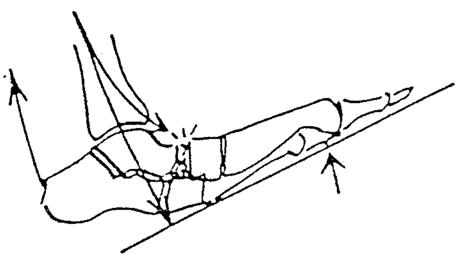

Figure 3.3: Fracture of the navicular, crushed during the push-off phase.

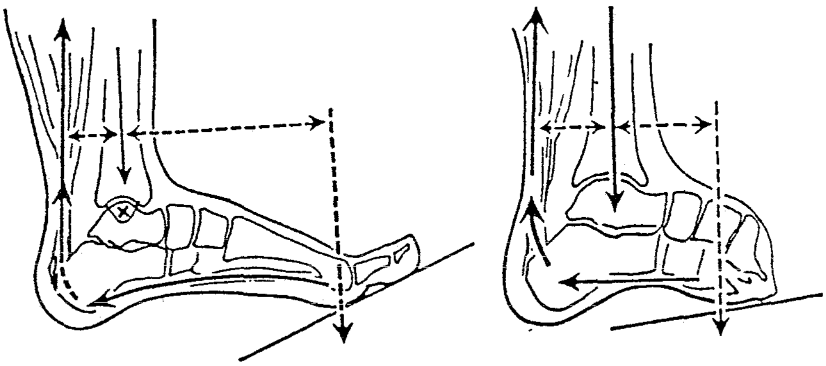

Figure 3.4: (a) Normal foot; (b) Short foot; For the same pull by the calf muscles, there is double the thrust on the end of the foot.

The short foot.

All these fractures and dislocations of the foot occur commonly in feet of normal length. As the foot shortens because of progressive absorption of the metatarsals so the length of the lever becomes shorter and the strain on the middle of the foot becomes less. Although the long foot is more liable to tarsal disintegration, the short foot has troubles all of its own. The muscles of the leg are balanced for the normal foot. The fore foot is three times as long in front of the ankle as the heel is behind. Therefore, the muscles that lift the heel have to be strong enough to lift the body against a three-to-one mechanical disadvantage. A man of 80 kilos (800 N) standing on one leg with his heel just off the ground is pressing down through his metatarsal heads with 800 Newton, but he is pulling up his heel with 2400 Newton. If the forefoot is shortened by absorption until only the metatarsal bases remain, there may be only as much foot in front of the ankle as there is behind (fig 3.4). The muscles that lift the heel, however, are just as strong and, even if there is no paralytic foot drop, the tendency is for the heel to be pulled up too much and the fore-foot to thrust down too much. The patient tends to stand on the end of his foot and concentrate pressure on the scar in that position. The high pressures on the front end of the foot produce a progressive ulceration and shortening.

3.4 Pressure patterns

The dominant characteristic of the pressure distribution of an ulcerated leprosy foot is the presence of local regions of abnormally high pressure, usually situated in the forefoot and the heel. In a previous study, the positions of maximum load were found to coincide with the sites of ulcers. The evidence shows that high local pressure correlates with plantar ulceration in leprotics with neuropathy. In the early stage of leprosy, high pressures in the forefoot and heel, in combination with insensitivity of the foot, can be an indication for possible future foot problems (see chapter 5). These foot problems and resulting damage can be prevented by early diagnosis and treatment.

Chapter 4 : Foot pressure measurement

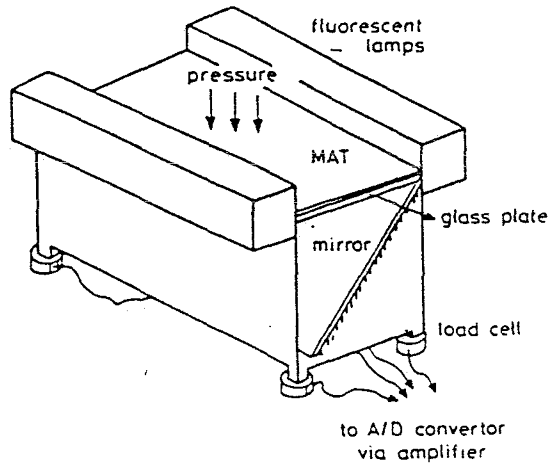

Figure 4.1: Schematic diagram of the barograph mounted on load cells.

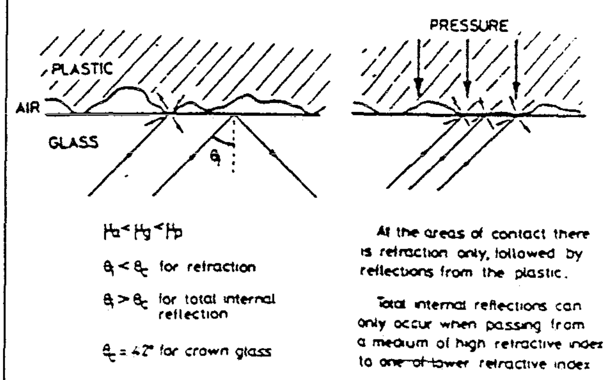

Figure 4.2: Diagrammatic representation of the physical principles of operation involved at the plastic/glass interface.

Image forming

The basic system of the barograph consists of a thick glass plate (180 cm * 45 cm * 1.25 cm), illuminated at the two opposing edges by fluorescent lights so that it behaves like a light 'pipe' with total internal reflections occurring at the glass/air boundaries. The glass plate is covered by a thin sheet of soft white plastic upon which the patient stands or walks (see figure 4.1).

The principle by which the method operates is due to the '*breakdown of total internal reflection of light*'. This is illustrated in figure 4.2. Light which enters the glass plate from its edges is totally internally reflected between the top and bottom surfaces of the glass. Total internal reflection can only occur when the light ray travels from a high refractive index medium to a low refractive index medium, i.e. from glass to air. However, when pressure is applied to the foil, and the plastic sheet comes into contact with the glass, total internal reflection can no longer occur because the plastic has a higher refractive index than glass. At a microscopic level, the plastic sheet has a rough surface and increasing the pressure increases the area in contact with the glass, so light rays refract out of the glass and scatter in all directions from the white foil. Thus an image of the pressure pattern, as shown in figure 4.3, can be seen from a 45° inclined mirror placed below the glass plate. The dynamic foot images as the person walks are processed using an image processing software, specially developed for on-line measurement at the Biomedical Engineering Division, IIT, Madras. The image processing involves first capturing of the background image of the barograph before the person walks and subtracting this image from the images of soles of feet obtained during walking. This results in an image of the footprint, where intensity at any point is related to the pressure under the sole of the foot. Thus a person standing barefoot or walking over the barograph will produce an instant, continuous pressure distribution display which can be used for further processing in order to extract relevant information in biomechanics or medical diagnostics [Chodera, 1985].

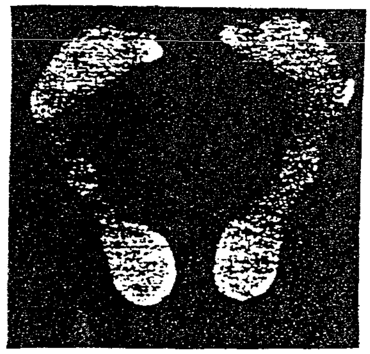

Figure 4.3: a typical gray scale display of the foot pressure distribution. the intensity of the image is related to the applied pressure.

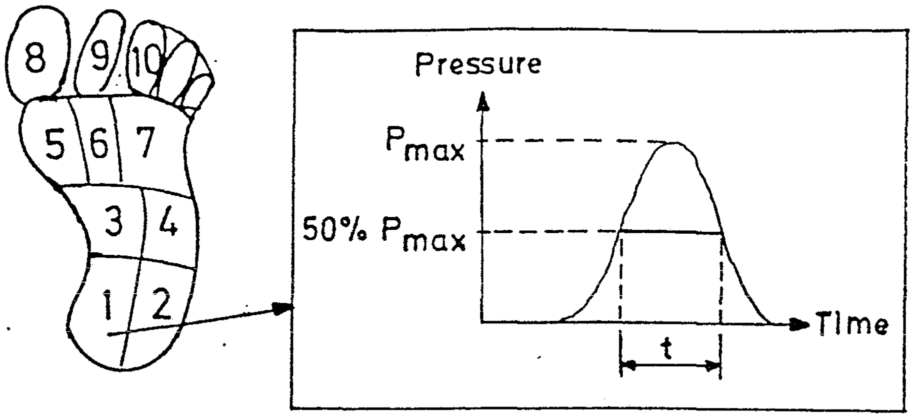

Figure 4.4: *Different areas of the foot and definition of contact time per area.*

The most critical part of this apparatus is the plastic to glass interface. An ideal material would have a linear light output change against applied pressure, would not show calibration changes with temperature, would not show visco-elasticity (which results in strain rate dependence and also in a steady increase in light output as a constant pressure is applied) and would not stick to the glass [Franks et al.,1987]. If the plastic surface is too smooth, the areas of contact are patches of light rather than spots, giving poor spatial resolution of the pressure distribution. It would also stick easily to the glass.

Measurement and analysis of pressures under the foot during walking is clinically useful in planning and assessing a number of orthopaedic procedures [Franks et al.,1983]. It may also be useful in the management of patients by aiding in the correct design of orthopaedic footwear and appliances. Clinicians are aware of the need to predict patients at risk of ulceration and to understand the mechanism of ulceration, and they are looking to foot pressure measurement as a prime investigation tool. In leprosy patients, early recognition and treatment can prevent paralyses and damage to the foot. More generally throughout orthopaedic and rehabilitation practice, clinicians are wishing to introduce more objective assessments into foot management.

The majority of foot skin ulcers among patients occur on the plantar surface, a fact which is not surprising when one considers the pressure the plantar skin is exposed to even during normal walking. previous studies found that ulcers occur on places of the highest plantar pressures. The primary function of the foot is locomotion. Therefore in the examination of the foot by pressure measurement, dynamic measurements taken during walking are very important. Where the function of the foot is disturbed, then this can be expected to reflect in abnormal plantar pressure during gait. The normal (not shear) component of forces under the plantar surface of the foot can now be measured as plantar pressure distribution. During the past century, many attempts have been made to develop a technique for the measurement of the distribution of pressures underneath the sole of the foot. In recent years, Betts and colleagues described a pedobarograph for pressure distribution measurement [1,2,7,8]. These measurements used a barograph which was only suitable for measurement of one foot only. As both feet are effected in leprosy, Patil et al.,1990 developed a barograph which could measure the static and dynamic foot pressures under both feet simultaneously (see figure 4.1). In our study, an attempt has been made to predict the stage of leprosy a patient is in, and to recognise early stages of possible foot problems.

We selected 10 distinct areas in the foot as shown in figure 4.4. These areas are individually scanned, and the point where the peak pressure has a maximum value in the particular area is used for comparison with other data. So now there are ten points for comparison per foot available. In these points, two indices have been calculated, and with the aid of these indices, a comparison can now be made on the patients data against 'normal' data.

1. Absolute values compared with mean of a reference (normal) population.
2. Absolute values compared with the range (25^{th} to 75^{th} percentile) of a reference population.

Clinically, the peak pressure alone is not the most relevant indicator of impending skin damage. The transient pressures exceeding the normal range of values may not necessarily lead to ulceration. The second critical factor to be taken into account, is the duration of any high pressure. For the analyses of foot pressure patterns two indices has been used. First there is the contact-ratio index (CRI), which takes into account the contact time of the specified area as a percentage of the total foot contact time:

$$CRI = 100\% * [\frac{t}{T}\frac{P}{W}]$$

t = time that 50% of the peak pressure is acting on specified area of the foot (see figure 4.4).
T = total contact time of the same foot.
P = 50% of peak pressure in specified area on the foot.
W = weight of the subject.

Secondly there is the pressure-time index (PTI), which is defined as the area (integral) under the pressure-time graph normalized for the weight of the person. Other important factors could be the peak pressures, the rise time to peak pressure etc.

We divided the patients into different categories, according to the kind of foot problems, and the stage of leprosy they are in. However, every patient is unique, and these groups are only meant to give an indication of the differences in the pressure-time index and the contact-ratio index between the categories. These are the categories:

I Insensitive foot and clawing of toes.
1. early stage: clawing of toes or flattening of arch (intrinsic paralysis)
2. 2^{nd} stage: severe clawing of toes.
3. advance stage: bone in forefoot damaged after severe clawing of toes or absorption of toes.

II Drop foot.
1. early stage: high pressures or scar on lateral border.
2. advance stage: ulcer and high pressure or CRI on lateral border.

III Bone changes.
1. early stage: decalcification or osteoporosis, fuzziness in joints, decrease of joint space, disappearance of trabeculae.
2. 2^{nd} stage: damaged joint or bone, or shortening of foot by absorption of toes.
3. advance stage: destruction of bones.

table 4.1: *Different groups in which the patients are divided.*

In table 4.1, the patients are divided into three groups according to the kind of foot problems; respectively insensitive feet and clawing of the toes, occurence of drop foot, and bone changes. These groups are further subdivided into two or three sub groups according to the early or more advance stage of the foot problems. When a patient has different kind of foot problems, the feet of one patient can be classified into more than one category. Now, measurements of foot pressures can be made on patients from these different categories and compared with the pressures taken from 'normal' subjects. The results are given in chapter 5.

Chapter 5 : Results

Standing foot pressure distribution.
Preliminary results show that pressure distributions under normal feet are even and symmetrical. Foot pressures for leprosy subjects are uneven, localised and unsymmetrical.

Walking foot pressure distribution.
In normal walking, the trace of vertical component of the reaction force against time has a double hump form. The pattern is characterised by clearly defined phases of heel-strike, mid-stance and push-off. The foot first makes contact with the floor at heel strike, and a very short duration transient spike may occur. The foot progressively rolls into contact with the floor and the force builds up to its first sustained peak. After a fall off to just below body weight, the force reaches a second peak before rolling off at the and of the step. The pressures are the highest in push-off, followed by heel-strike and mid-stance.

Path of centre of pressure.
Heel strike occurs well back on the heel and the centre of foot pressure (CFP) moves rapidly forward as the force builds up. By the beginning of single support phase the forefoot is also in contact and as a result the CFP moves along the midline towards the midfoot region. Thus the first peak is reached when the CFP is well forward of the ball of the heel and the metatarsal heads have made contact. The second peak occurs as the heel is leaving the ground and the toes are in contact. The normal walking pressure distribution show a smooth variation devoid of any abrupt changes in pressures. path of centres of pressures show a smooth (nearly sinusoidal) variation. It is emphasised that the forces on the heel and the forefoot are of broadly similar magnitude but the duration is longer for the forefoot. These results suggest that the load-bearing function of the forefoot is about three times that of the heel.

In leprosy subjects, there is absence of a well defined heel-strike, due to foot-drop. Non participation of the toes in push-off phase due to intrinsic paralysis. The path of centres of pressures show a zig-zag variation and also indicating load being taken by the central portion of both the feet.

The different categories as indicated in table 4.1 can be recognised by the pressure-time index as well as by the contact ratio index. The results suggest that in the early stages of leprosy, the contac-ratio index is a good indicator for intrinsic muscle paralysis (insensitive feet and clawing of toes), and also shows the early stages of drop-foot. In the early stages of leprosy, difference was found between normals and patients, especially in areas 1,2,5,6,7 (see figure 4.4) thus under the heel, and the metatarsal heads. Thus, when checking a patient, any differences between a patient and the normal values in these areas may indicate early stages of possible foot-problems.
We analysed the following number of feet in each categorie; normals: 20 feet, I-1:17, I-2:4, I-3:4, II-1:5, II-2:2, III-1:22, III-2:5 and III-3:6 feet. For the statistical analysis, the computer program "Statgraphics" has been used. The statistical results are calculated with a 95% confidence interval for the mean.The range of the values of the contact-ratio index for the medial heel area are shown in figure 5.1. The boxes represent the range of values (25^{th} to 75^{th} percentile population). In this figure differences can be seen between the different categories of leprosy patients and the normals for almost all the categories. We expect that after analysing more data, the differences between the categories become even more clear. In the figures 5.2 to 5.4, the mean values of the contact-ratio index as function of the areas of the foot are given for the different categories as indicated in table 4.1. In these graphs the typical graph of normals is also shown. There is a clear difference between the the different stages of leprosy for almost all the areas shown in the graphs. The pressure-time index did not show any typical differences between the groups. We expect that using the integral of the pressure-time graph (not normalized for the weight of the person) might give better results.

Finally, the influence of foot-drop correction has been investigated. At the moment of study, there were not enough data available for a statistical analysis, but for individual patients, the results can be shown as in figures 5.5 and 5.6. In these figures, the normal range is also shown. The analysis were taken 3 months and 10 months after operation respectively. There is a great decrease in pressure in the metatarsal heads and in the heel-area after 10 months. Three months after operation, there is not much difference with the values before operation.

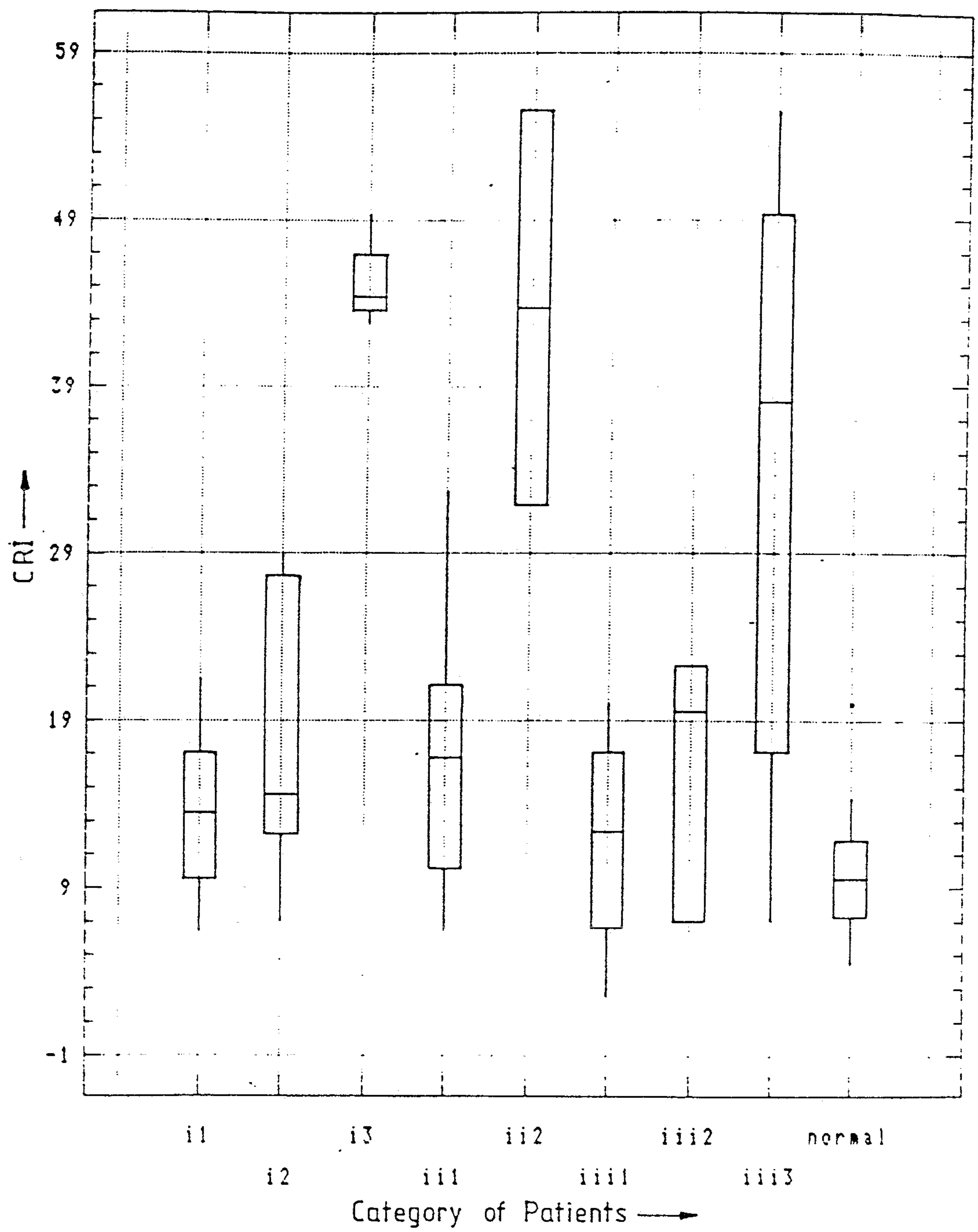

Figure 5.1: range of values of CRI for different groups in area 1 (medial heel)

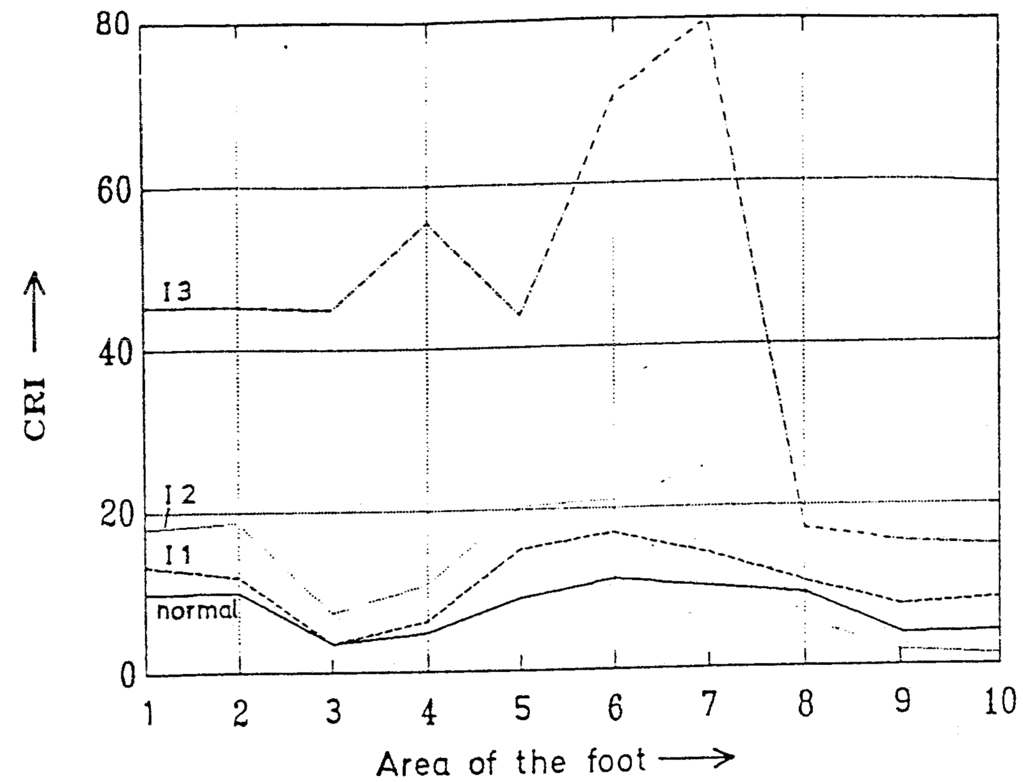

Figure 5.2: mean values of contact-ratio index for group I

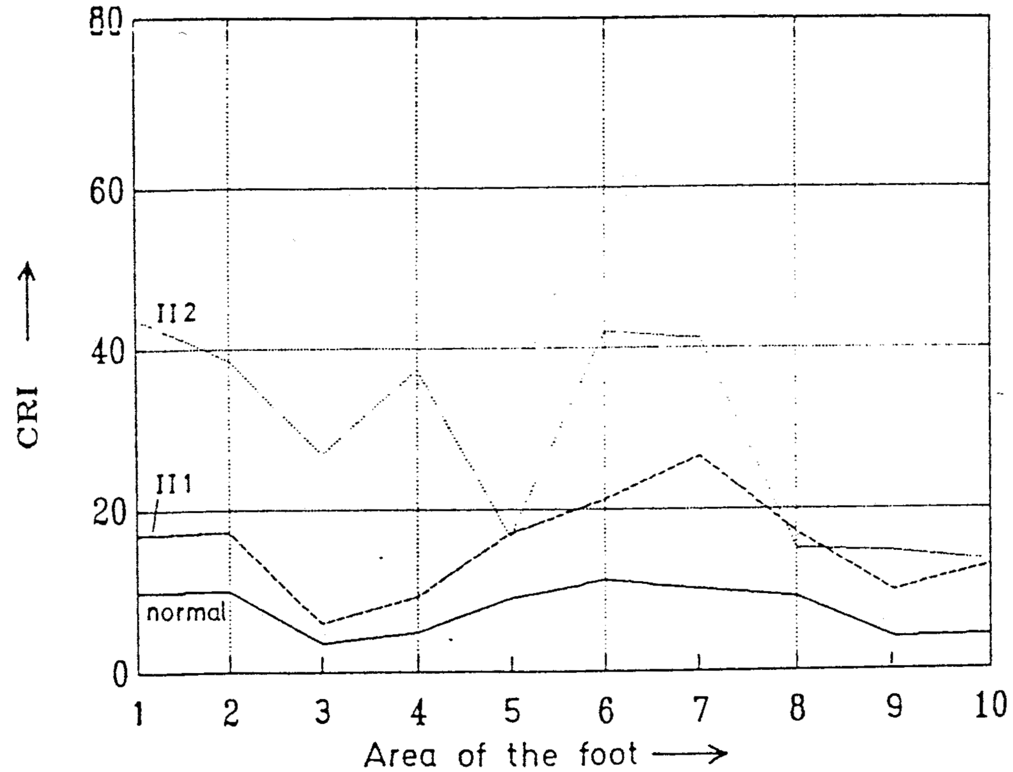

Figure 5.3: mean values of contact-ratio index for group II

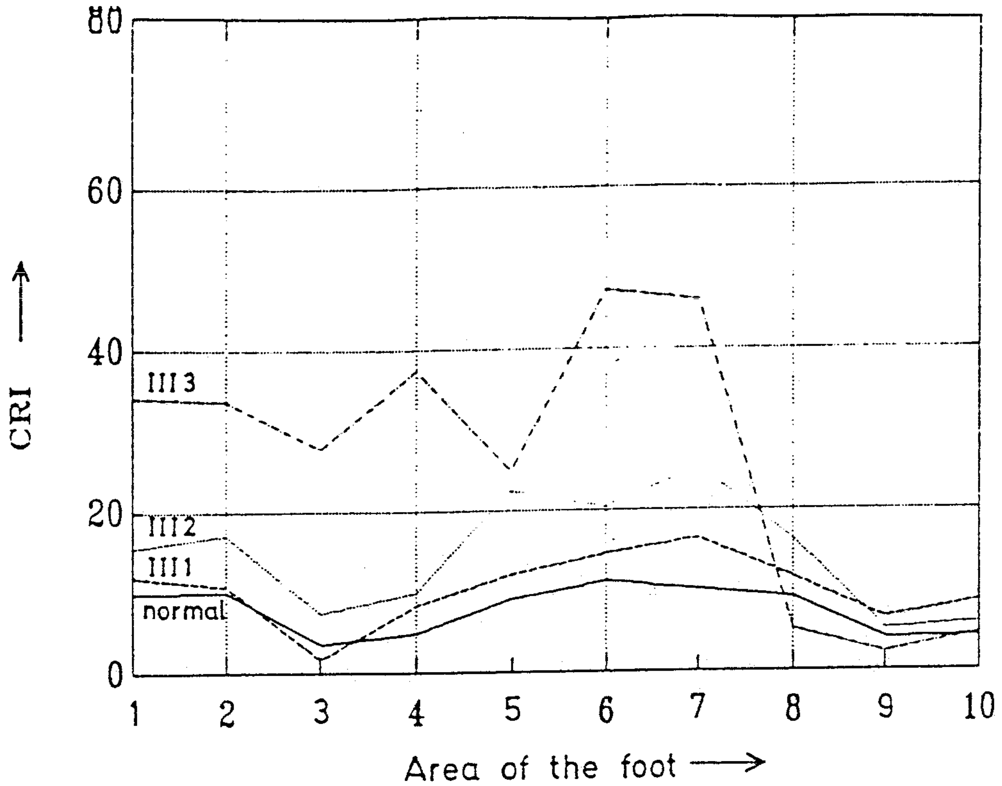

Figure 5.4: mean values of contact-ratio index for group III

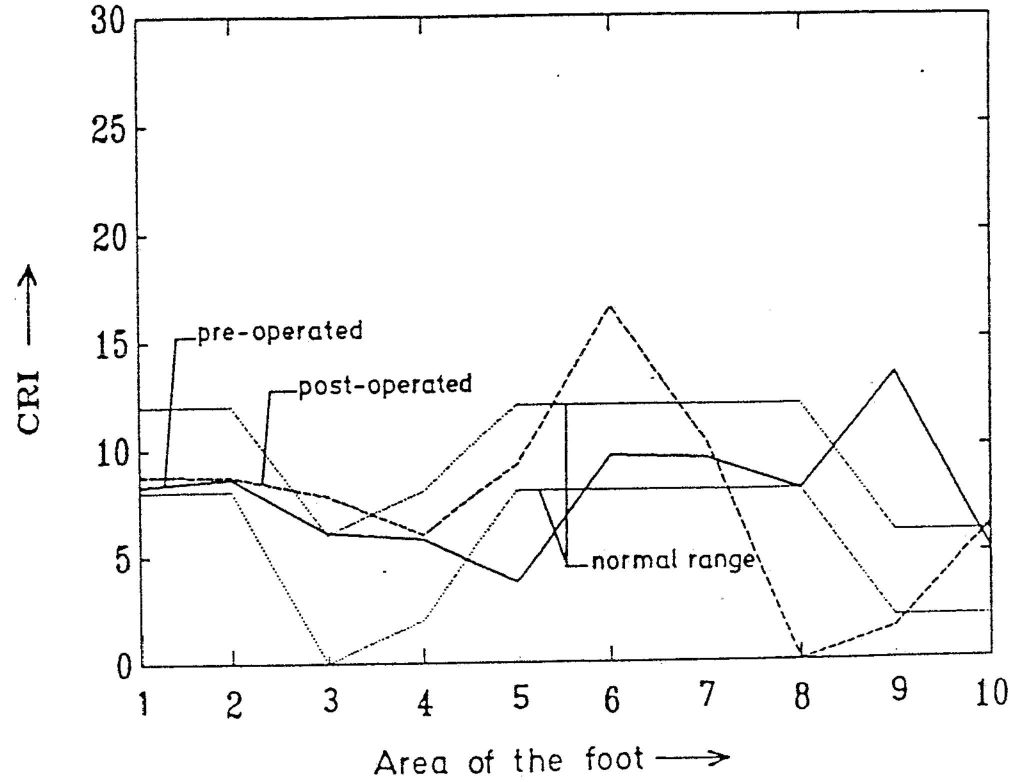

Figure 5.5: *contact-ratio index before and after foot-drop correction (3 months)*

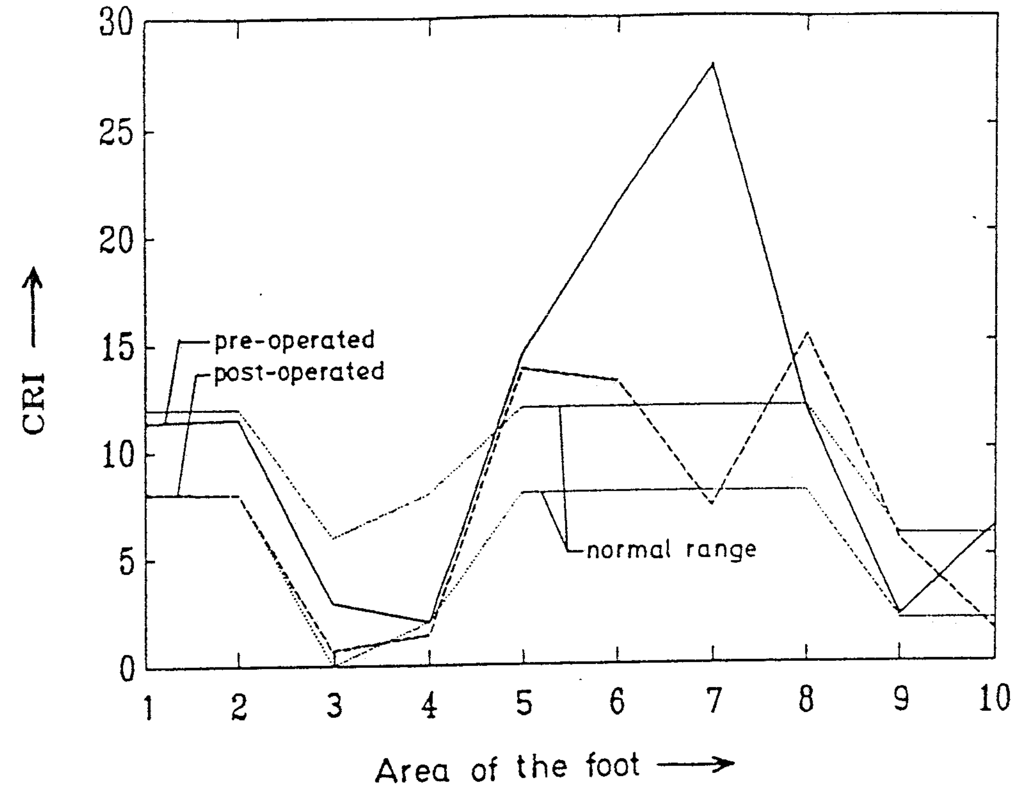

Figure 5.6: *contact-ratio index before and after foot-drop correction (10 months)*

Chapter 6 : Conclusions & recommendations

Previous papers [Franks et al.,1983] have described the application of the system in orthopaedic practice to the management of patients undergoing forefoot reconstruction surgery. With the availability of a simple and quick to use system it is now possible to extend the use of the system to a range of other foot problems. The area of our interest is the management of leprosy patients with foot ulcers, including the detection of leprosy patients at risk of developing ulcers. The same method could be used on diabetic patients.

The most useful application of this technique in the future is to patients who are in the early stages of the disease, who appear to be at high risk for ulcer development and yet exhibit no lesions at the time of study. Once the regions of abnormal pressure distribution have been recognised, a variety of treatment regimes could be instituted to prevent breakdown of the foot. Pressure distribution measurement could also play a significant role in the evaluation of the success of the various treatments as surgical correction of dropfoot.

7.1 Conclusions

It has been shown that foot pressure measurements using a barograph can be very useful in quickly making measurements on a number of leprosy patients to arrive at possible causes of foot ulcers and early diagnosis of tarsal disintegration as well as assessing effectiveness of corrective orthopaedic procedures. The greatest advantage of this system is that conclusions can be made about the performance of the walking foot while the patient is still in the clinic. Thus the biomechanical effects of orthotic devices such as shoe inserts, braces, and callipers can be demonstrated as soon as fitting has been completed, and corrections or modifications made to these aids as necessary.

This study shows that in the early stages of leprosy, the contact-ratio index is a good indicator for feet with intrinsic muscle paralysis (insensitive feet and clawing of toes), and also shows early stages of drop-foot.The early stages of drop-foot results in a higher contact-ratio index on the lateral border of the foot, due to peroneal paralysis. For advanced stages of leprosy, both the contact-ratio index and the pressure-time index will be higher compared to normal subjects. The areas which differ the most from normal subjects were found to be the heel area, and the metatarsal heads.

A further and important factor regarding the mode of foot placement in the patients is concerned with balance. If the toes are dorsiflexed the area of the base of support is effectively reduced. It may be that placing the whole foot on the ground is a compensation for the absence of toe function, and helps the patient to maintain balance during gait. Finally it must be recognised that the patients are walking in such a way so as to reduce pain under specific areas of the foot, and thus enable them to be mobile for longer periods of time. For leprosy patients with insensitive feet of coarse, no pain can be felt by the patient. He is therefore unable to react on pain, and may damage the foot without knowing it.

In conclusion two essential aspects of the use of the barograph should be emphasised. As with any other diagnostic technique there are technical limitations for the validity of the data observed (plastic, TV camera and microprocessor used etc.). However, the major variable is the human factor. The human gait and standing are extremely complex phenomena. No standardisation of recording conditions will ever be comprehensive enough to replace the skill, judgement, experience and knowledge of the user. The barograph will only produce information on pressure distribution for which it has been designed.

7.2 Recommendations

Further investigation is necessary about the influence of different parameters on the contact-ratio index as well as the pressure-time index. these parameters could include; the temperature, the weight of the person, the velocity of the person etc.

Further investigation could also include the influence of shear stress onto the plantar surface of the foot. Lord et al., 1986 reports a study which found that, in the presence of shear, the level of direct pressure needed to occlude blood flow was reduced by 50% .
When analysing a patient it could be useful to use earlier measurements of the same patient to indicate change, and also to make a comparison with the contra lateral foot to reveal asymmetry.
Johnson, 1981 reports on an interesting method of data reduction and graphical representation of pressure distribution; more of this type of approach is probably necessary in order to facilitate comparison of clinical presentations against 'normal' standards. Dr. Johnson prefers the term *'pelmatobarography'* to pedobarography, finding etymologically displeasing the Latin-Greek mixture of `pedo' and `baro'.

in addition, the following suggestions are given which can be used when analysing a patient.

Suggestions for analysis of patient data in relation to foot disorders

1. Check for kind of leprosy. It's important to know what kind of leprosy a patient has, because lepromatous leprosy or border-line leprosy may cause leprosy osteitis which may in turn cause weakening of the bone, and resulting in the collapse of bone.
2. Check if and which part of the foot has become insensitive. In insensitive feet, the ability of sweating is also lost.
3. Check for paralysis of the posterial tibial nerve (this results in insensitive feet, or intrinsic paralysis) resulting in clawing of the toes, or weakening of the "bowstring" of the arch of the foot.
4. Check for paralysis of peroneal nerve (in case of foot drop the dorsiflexors and the evertors are paralysed).
5. Check for open ulcers, and if the patient walks unprotected. This may cause osteomyelitis by infection going to the bone. The unprotected bone becomes more deeply infected, the surface of the bone crumbles away and becomes eroded. As a result, the nearby joints become infected, dislocated and destroyed. Thus, if infection has started at the metatarsal heads, it may after further walking infect the tarsal bone and destroy the arch of the foot.
6. Check if the X-ray of the foot shows decalcification or osteo-porosis of the calcaneus bone. This may be indirectly observed in foot pressure variation on the sole of the foot (contact-ratio index may change).
7. Check for high impact at heel strike. High impact under the heel during heel strike, if calcaneum is decalcified may result in calcaneum bone damage.
8. When the heel bone becomes fractured or weakened by sepsis, the strong calf muscles pull up the back half of the heel bone and then the weight of the body will be taken through the centre of the foot. This nearly always results in serious ulceration's leading to destruction of the whole foot.
9. Mid-stance. Check for peroneal muscle paralysis, and if this is the case, check if foot is slightly inverted and if it has high pressures or high CRI or high PTI at its lateral border. Check for untreated ulcer in the lateral border. If this exists and CRI is high, this could give rise to sepsis and leads to severe septic destruction of the bones in the centre of the foot. Indications are: (i) The foot is slightly inverted. (ii) If drop foot over correction (too much pull on the inner side of the foot) is done in peroneal muscle paralysis. (iii) This leads to lateral border walking. If ulcer exists on the lateral border, this can lead to sepsis and bone destruction in the central part of the foot.
10. Push-off. If partly paralysed foot (possible insensitive), if arch is getting flattened, and the person takes strong thrust in the forefoot such that there is high pressure in the forefoot, this may result in

bones at the centre (usually the navicular) to break and the foot then becomes flat and may even bend so that the arch is reversed, and unable to take any thrust and then the foot get destroyed. Check for partly paralysed foot (insensation) if arch is flattened and has high pressures in the forefoot, and high CRI in forefoot. This may lead to breaking of the central foot bones.

11. Short foot due to metatarsal absorption. Short foot produces high pressures in the forefoot, possibly giving rise to high CRI. Check for shortened foot by metatarsal absorption.
12. Check for peroneal paralysis, foot drop and inversion of the foot, if the lateral border gets high pressures and high CRI.
13. Check for posterior tibial paralysis, this causes sensation loss of the foot, intrinsic paralyses resulting in clawing of the toes. (i) In moderate clawing high pressures in tip of toes (high CRI). (ii) In severe clawing high pressures on metatarsal heads (high CRI).
14. Check for speed of walking. High speed causes high pressures on metatarsal heads in push-off.
15. Check for healed scar or unhealed ulcer in the sole of the foot.

Bibliography

1. Betts, R.P., and T. Duckworth.
A device for measuring plantar pressures under the sole of the foot.
Engineering in Medicine, 7:223-228, 1978

2. Betts, R.P., T. Duckworth, and I.G. Austin.
Critical light reflection at a plastic/glass interface and its application to foot pressure measurements.
Journal of Medical Engineering & Technology, 4:136-142, 1980

3. Brand, P.
Leprosy today; Insensitive feet, A practical handbook on foot problems in leprosy.
The leprosy mission international, 1989

4. Cavanagh, P.R., E.M. Hennig, M.M. Rodgers and J. Sandersson.
The measurement of pressure distribution on the plantar surface of diabetic feet.
Biomechanical measurement in orthopaedic practice, 5:159-166, Clarendon Press, Oxford 1985

5. Chodera, J.D.
Pressure under the soles in upright man.
Proceedings of the international conference on biomechanics of hand and foot, Madras, 1985

6. Facey, O.E., I.D. Hannah, and D. Rosen.
Analysis of the reproducibility and individuality of dynamic pedobarograph images.
Journal of Medical Engineering & Technology, 17:9-15, 1993

7. Franks, C.I., R.P. Betts, and T. Duckworth.
Microprocessor-based image processing system for dynamic foot pressure studies.
Medical & Biological Engineering & Computing, 21:566-572, 1983

8. Franks, C.I., and R.P. Betts.
Selection of transducer material for use with `optical' foot pressure systems.
Journal of Biomedical Engineering, 10:365-367, 1988

9. Huson, A.
The human tarsus as a closed kinematic chain.
Proceedings of the international conference on biomechanics of hand and foot, Madras, 1985

10. Jenkins, D.B.
Functional anatomy of the limbs and back.
W.B. Saunders company, Alton, Illinois 1991

11. Johnson, F. and D.M.C. Kong
Comparative display of dynamic foot-ground pressure data (pelmatobarography)
Engineering in medicine, 10:159-161, 1981

12. Lord, M., D.P. Reynolds and J.R. Hughes
Foot pressure measurement: a revieuw of clinical findings.
Journal of Biomedical Engineering, 8:283-294, 1986

13. Patil, K.M. and M.S. Srinath
New image-processing system for analysis, display and measurement of static and dynamic foot pressures.
Medical & Biological Engineering & Computing, 28:416-422, 1990

14. Patil, K.M., M. Babu, R. Manoj, P.K. Oommen, and G.N. Malaviya.
Measurement and analysis of dynamic foot pressures in normals and leprosy patients.
Recent advances in Biomedical engineering, Proceedings of ICRABME'94, Hyderabad, India 1994

15. Soames, R.W., P.G. Carter, and J.A. Towle.
The rheumatic foot during gait.
Biomechanical measurement in orthopaedic practice, 5:167-178, Clarendon Press, Oxford 1985

16. Stokes, I.A.F., I.B. Faris, and W.C. Hutton.
The neuropathic ulcer and loads on the foot in diabetic patients.
Acta Orthop Scand, 46:839-847, 1975

17. Whittle, M.
Gait analyses.
Butterworth-Heinemann Ltd., Oxford 1991

Glossary

Abduction	Movement away from the midline.
Adduction	Movement toward the midline.
Abduction/Adduction	Movement of the toes away from/toward the long axis through the second digit.
Anatomical position	Erect position with heels together, feet pointing somewhat laterally, arms by the sides with the palms facing anteriorly.
Anterior (ventral)	Toward the front of the body. (opposite of posterior.)
Aponeurosis	A flat, broad tendon.
Cartilaginous joint	A joint at which bones are united by cartilage.
CRI	Contact ratio index, Indicator of the contact-time of a certain area as a percentage of the total contact time of the foot
Deep	Farther from the surface.
Diabetes	Dissease in which control of bloodsugar is imperfect, through lack of, or abnormal response to, the hormone insulin.
Diabetic neuropathy	Loss of function of peripheral nerves, especially sensory nerves in the feet, due to diabetes.
Digits of the foot	The five toes; can be numbered from one through five, beginning with the big toe.
Distal	Away from the rest of the body; the toes are the distal part of the foot.
Dorsal	The posterior surface of the body. (opposite to ventral.)
Dorsiflexion	Movement at the ankle joint in which the toes are brought closer to the anterior surface of the leg (toes up), as in standing upon the heels.
Eversion	Turning the sole of the foot outward.
Extension	Straightening out of a bent part.
External (lateral) rotation	Rotation about the long axis, so that the anterior surface is turned outward from the body.
Fascia	Connective tissue sheet or membrane that envelopes or binds together other structures.
Fibrous joint	A joint at which bones are united by fibrous material.
Flexion	Banding at a joint, which decreases the angle between two parts; in flexion of the leg at the knee, the leg moves posteriorly.
Hallux valgus	Deformity affecting the great toe, in which the metatarsophalangeal joint is in valgus.
Hansen's disease	Bacterial infection causing progressive destruction of nerves and sensory loss; also known as `leprosy'.
Inferior	toward the feet.
Insertion	Attachment of the muscle that is more movable (relative to the origin).
Internal (medial) rotation	Rotation about the long axis, so that the anterior surface is turned inward toward the body.
Inversion	Turning the sole of the foot inward; combines plantarflexion, supination and adduction).
Joint	Union between two or more bones.
Lateral	Away from the midline body; the little toe is on the lateral side of the foot.
Leg	Segment of the lower limb between the knee and ankle joints.
Ligament	In the skeletal system, an organized connective tissue band that binds bones together.
Medial	Toward the midline of the body; the big toe is on the medial side of the foot.
Origin	Attachment of the muscle that is more fixed (relative to the insertion).

Peripheral neuropathy	Loss of function due to degeneration of the nerves of the hand and feet.
Plantar flexion	Movement opposite of dorsiflexion, as in rising upon the toes.
Posterior (dorsal)	Toward the back of the body.
Pressure sore	Ulcer forming on an area of skin exposed to sufficien pressure to cut off blood supply.
Pronation	Rotation about the long axis of the foot (soles turned outward)
Proximal	Closer to the rest of the body; the shoulder is the proximal part of the arm.
PTI	Pressure time index, integral of the pressure-time graph
Superficial	Closer to the surface.
Superior	Toward the head.
Supination	Rotation about the long axis of the foot (soles turned inward).
Tendo Calcaneus	Common tendon of insertion for the gastrocnemius and soleus muscles onto the calcaneus.
Tendon	Connective tissue cord or band that attaches muscle to bone.
Ulceration	Loss of covering skin or epithelium.
Valgus	Describe an angulation of a joint away from the midline; knock knees are in valgus.
Varus	Describe an angulation of a joint towards the midline; bow legs are in varus.
Ventral	The anterior surface of the body. (opposite of dorsal).