Measurement of pressure under leprotic feet using a barograph

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Abstract—This paper describes the measurement of pressure distribution under normal and leprotic feet using a barograph. The barograph consists of a glass plate illuminated at its edges by fluorescent lights. The top surface of the glass plate is covered by a thin sheet of opaque white plastic upon which the subject stands. Greater pressure levels cause more intimate contact between the plastic and the glass, which results in the breakdown of total internal reflections within the glass. When viewed from a 45 degree inclined mirror placed below the glass plate, the areas of contact of the foot can be seen with light intensity related to the applied pressure. The resulting image recorded photographically is scanned for pressure intensity patterns using a microdensitometer. The pressure intensities are calibrated using known weights over specified areas. The method establishes characteristics of pressure distribution under normal feet. It confirms that scars resulting from healed ulcers in leprosy subjects are discrete sites of very high pressures in the range of 90 to 110 N/cm². This is two to three times the pressure levels under normal feet. Scar regions combined with deformity of the foot increase these pressures to still higher levels and possibly cause ulcers. The quantitative values of pressures determined in this study for leprosy subjects during standing are helpful in identifying problem areas on the soles of the feet.

INTRODUCTION

Leprosy is caused by a bacterium called Mycobacterium leprae, commonly known as leprosy bacillus or Hansen’s bacillus. According to the 1981 census, 4 million people—about 6 out of every 1,000—in India have leprosy. Of these, 25 percent suffer from physical deformities. Leprosy bacilli attack the nerves, causing loss of sensation and muscular paralysis, which leads to physical deformities if the patient is not given early treatment. Such nerve damage is irreversible and there is no hope for regeneration. Since the mycobacterium leprae attack directly on neurons, many leprosy patients have no sensation at the affected sites.

Excessively high stress on the leprotic foot for prolonged periods causes many problems. Experimentally, it was shown that high stresses for prolonged periods cause mechanical damage to skin and soft tissue by cutting off the blood supply to the tissue (3,4). At sites where pressure is abnormally high such tissue damage will occur without the patient’s knowledge. To minimize further damage to the tissue, special footwear needs to be designed that will redistribute high pressures. The quantitative knowledge of pressure distribution under the leprotic foot is helpful in identifying problem areas on the sole of the foot.

In this paper, pressure distribution under standing feet is studied using a barographic technique wherein the pressure intensities are converted into intensities of light.
MATERIALS AND METHODS

Numerous methods have been proposed for measuring pressure distribution under the sole of the foot while standing. These methods have ranged from the use of simple to extremely complex measurement devices. Early attempts to obtain the load distribution under the foot were qualitative measurements made from impressions in plaster, mud, clay, or other suitably deformable substances. However, because the load measuring medium is deformable, such methods tend to measure the shape of the foot rather than the detailed load distribution. In contrast to the early measurement techniques, which were largely qualitative, recent methods have provided more quantitative information about pressure distribution. For the purposes of this study, a barographic technique was used.

The barograph consisted of a thick glass plate (1.8m × 0.45m × 0.0125m) and a plane mirror placed below the glass plate at an angle of 45 degrees in a wooden box (Figure 1). The glass plate was illuminated by fluorescent lights along its longitudinal thickness. The top surface was covered by a thin opaque white plastic sheet upon which the subject stood. When viewed from the 45 degree inclined mirror placed below the glass plate, the areas of foot contact could be seen with light intensity related to the applied pressure, due to the phenomena of "breakdown of total internal reflection." The physical principle involved in the operation of the technique was illustrated at length in Betts, et al. (1). The resulting image recorded photographically was scanned for pressure intensity patterns using a microdensitometer. Pressure intensities were calibrated using known weights over specified areas.

RESULTS AND DISCUSSION

Figure 2a shows the footprint of a normal subject during standing. The image of the footprint as seen from the barograph gave the qualitative pressure distribution, whereas quantitative pressure distribution was obtained by scanning the photographic negative of the footprint using the microdensitometer. Figure 2a indicates the presence of a clear medial arch. Light intensities appear to be evenly distributed from the medial to lateral side and from forefoot to hindfoot.
Figure 2b shows the quantitative distribution of pressure on the sole of normal feet, which is divided into 16 zones consisting of five each for toes and metatarsal heads and three each for midfoot, heel regions, respectively. The following observations were made from the quantitative normal pressure distributions:

1) The peak pressure in any part of the sole of the feet did not exceed 35N/cm² (350 kPa).

2) The peak pressure ratios of forefoot to hindfoot as well as medial to lateral foot were found to be nearly the same. This is in agreement with the results of Betts, et al. (2).

3) Symmetrical pressure patterns were seen between the left and right foot.

4) The ratio of peak pressure to mean pressure under the feet was equal to 14.1.

Similar foot pressure distribution measurements were made on 16 normal subjects. The ratios of peak pressure to the mean pressure, with 95 percent confidence interval, was in the range of 13.8 to 19.3, and no localized high pressure zones were observed. Peak pressure ratios of the forefoot to hindfoot were found to be nearly equal to unity with a significance level of five percent.

The pressure distributions under the feet of representative leprosy subjects with deformity and scar tissue are illustrated in Figures 3 and 4. Figure 3a shows the footprints of a leprosy subject with flat feet. The toes of the left foot are either absorbed or amputated and therefore are not seen in the footprint. Clinical findings showed scars on the metatarsal heads and heels of both the feet. This was clearly seen in the footprints of both leprotic feet by high intensity light spots at the corresponding locations. Figure 3b presents the quantitative pressure distribution for leprosy subject "a". The pressure distribution showed high pressures of 110 to 130N/cm² (1100 to 1300 kPa) in the medial arches and healed ulcer scar regions of the metatarsal heads and heels. The abnormally high pressures were two to three times those of normal pressures.

Figure 4a shows the footprint of a leprosy subject with posterior tibial nerve motor and sensory paralysis of both feet. Scars were observed on the second and third metatarsal heads and heel of the left foot and the first metatarsal head and heel of the right foot. Figure 4b presents quantitative pressure distribution at different locations of the feet. The pressure distributions showed high pressures of 105N/cm² (1050 kPa; two to three times normal pressure value) in the healed ulcer scar regions.

Similar studies made on other leprosy subjects showed nonsymmetric pressure distributions between the left and right foot. The regions of scars due to healed ulcer showed high pressure zones; two to three times normal pressure zones. Foot deformity increased these pressures to a still higher level of 110 to 130N/cm² (1100—1300 kPa) and possibly caused ulcers.
CONCLUSIONS AND FUTURE PLANS

The barographic method of finding pressure distribution on the sole of the foot during standing established characteristics of normal pressure distribution patterns. In leprosy subjects with foot abnormalities, the pressure distribution was not symmetric between left and right foot; instead, it gave rise to high pressure zones. The barographic study confirmed that the scars resulting from healed ulcers in leprosy subjects were discrete sites of very high pressures of 90 to 110N/cm² (900–1100 kPa; two to three times normal pressure). Foot deformities increased these pressures to a still higher level of 110 to 130 N/cm² (1100 to 1300 kPa), and possibly caused ulcers. The quantitative values of pressures determined here for leprosy subjects were of great help in identifying problem areas on the sole of the foot. The study will seek to identify peak pressure areas when the heel is lifted during walking.

Presently, the barograph helps the analysis of the bare foot on a flat surface. A future plan is to computerize analyses of barographic foot pressures for use in studying pressure patterns during walking and in designing shapes of footwear insoles and inserts fitted under the insoles for leprosy patients.

Footwear design will include the following procedures. Barographic pressure patterns under a thin insole material of 2 mm thickness with a flat bottom surface will be recorded. The shape of the insole material will be varied, and correlations between insole material shape and pressure patterns under the insole of both normal and leprosy subjects will be determined. If a positive correlation is achieved, we may be able to generate a footwear insole shape for leprosy subjects that redistributes and minimizes areas of high pressure, thereby preventing further ulcer formation or other damage to the soft tissue.

The effects on the pressure map of different preshaped inserts fitted under the insole of footwear worn by leprosy patients with foot deformities also will be studied. The final goal is to shape an insole on a computer monitor using data from the original pressure map and then transfer this shape into insole footwear material. It is hoped that the barographic pressure pattern study will assist in designing individualized footwear for leprotic persons.

REFERENCES