Measurement of pedal pressures
An illustration of a method

W. J. M. F. COLLIS* AND M. I. V. JAYSON†
From the * Royal National Hospital for Rheumatic Diseases, Bath, and the † Department of Medicine, University of Bristol

Although the feet are submitted to constant use, studies of the forces acting during walking have been limited. In this paper we present a technique for measuring the pressures under the different parts of the foot and describe the pressure pattern for normal feet and some of the changes that occur in rheumatoid disease.

Method

The pressures under the various parts of the foot were serially recorded by means of a thin transducer. This specially constructed transducer measured 11 by 12 mm. and was 2 mm. thick. It contained a silicon semiconductor strain gauge (Ether Electronics) mounted on Araldite between two plates of beryllium-copper. The remaining cavity was filled with silicone rubber. The strain gauge was distorted by any deflection of the front surface of the transducer and therefore in proportion to any applied pressure. The device formed one arm of a Wheatstone bridge, and the output from the bridge was amplified and recorded. Calibration using known pressures showed that, over the required range, a linear relationship existed between the applied pressure and the deflection of the recorder trace. By careful palpation, the metatarsal heads were identified and the transducer applied and fixed in position with thin adhesive tape. Similarly the device was applied to the heel. The subject walked barefoot in a straight line and recordings were made over many paces. The maximum pressure developed at each site during walking was estimated from the mean of twenty successive paces.

In practice we found that the subjects walked at different rates and applied their feet to the ground with different forces. The pressures recorded at the same sites in different subjects therefore varied widely. In order to make meaningful comparisons, the pressures at each site in the forefoot were related to those developed at the heel of that subject. By this means the pressure ratio under each metatarsal head was determined.

Subjects

Measurements were performed upon ten control feet, six from female subjects and four from males. On two occasions both feet of the same subjects were used and comparable results were obtained. Four measurements were performed upon left and six on right feet. Measurements were also made upon ten rheumatoid feet. The deformities of these feet varied widely and therefore the results were not considered as a whole but were individually compared with those from the normal subjects.

Results

In Fig. 1 are seen the pressure ratios from the five metatarsal heads in the normal feet. The highest pressures were recorded under the second and third metatarsals, with lower pressures under the first and fourth, and the least under the fifth. This pattern was consistently seen in each of the individual feet.

![Fig. 1 Mean and standard deviations of pressure ratios in control feet](image)

Fig. 2(overleaf) shows the pressure ratios in the foot of a man (Patient A) with rheumatoid arthritis. There was acute involvement of the fourth MT-P joint, which was painful to palpate, and the subject walked in such a fashion that the pressure on this joint was minimized. Although there was advanced involvement of all the other joints, the disease process was inactive and the pressures were relatively normal. Indeed there was increased pressure over the fifth MT-P head associated with subluxation of this joint.
Patient B (Fig. 2) had the third metatarsal head removed some 10 years previously. She tended to walk with all her weight on her heels and a grossly disordered gait with low pressures in the forefoot. The lowest pressures were recorded over the site of the third MT head with low pressures on both sides of it.

Patient C (Fig. 2) had acute inflammatory arthritis of the MT-P joints. The graph shows reversal of the normal curve of the pressure ratios and this was associated with acute involvement of the second, third, and fourth joints. In addition, there was acute involvement of the ankles, which made him unwilling to plantar-flex the foot during walking and therefore also reduced the pressures as a whole developed in the forefoot.

**Discussion**

Measurements of pressures under the moving foot present considerable technical difficulties. In the present technique the transducer itself had a finite thickness and therefore in itself altered the pressure dynamics. The device was constructed to be as thin as possible in order to minimize this error. In addition, the device when applied was mildly uncomfortable and might in itself have altered the pattern of walking. This is most likely to occur in rheumatoid subjects with painful joints, but none of the subjects complained of any real discomfort when specifically questioned regarding this. Wide variations in pressure measurements can be found and associated with alterations in a subject’s gait and speed of walking. For this reason we elected to compare the ratios of the pressures to that recorded under the heel rather than the absolute pressure measurements.

Previous measurements of pressures under the foot have been limited. Godfrey, Lawson, and Stewart (1967) employed a similar technique but they performed only a few studies and drew no conclusions about the distribution of pressures in the forefoot. Stroescu, Stoicescu, and Stoia (1971) employed a technique of ‘baro-podography’ to measure pressures under the various parts of the stationary foot. Few details of techniques or results are given, although they state that the highest pressures were found under the first MT head.

In contrast, our results in the normal foot demonstrate clearly that the highest pressures develop under the second and third MT heads during walking with the lowest pressures under the fifth MT head. If one analyses the sensation of walking on a flat surface it is possible to confirm this finding. Osteoarthrosis most commonly develops in the first MT-P joint and has often been ascribed to the pressures developing at this site. This hypothesis should be examined more critically as the pressures here are lower than in adjoining joints. It may well be that other factors, such as lateral squeezing by the shoe or the torque developed when the joint is flexed, are of greater importance. Again the fifth MT-P joint is a common early site for rheumatoid erosions and this might be ascribed to the high pressures acting here. Again, the pressures at this site are normally relatively low but lateral squeezing by the side of the shoe, by a tight toe-cap, or a high torque might be more important. A common disability in rheumatoid arthritis is the ‘centre-forward’ callosity (Dixon, 1970). This occurs in the site where the highest pressures are normally found, and it is likely that these pressures are responsible for this disability.

Wide variations in forefoot pressures were observed in the rheumatoid feet. Many different deformities play a part in the pathology of the feet and these were reflected in the different values found. For example, involvement of other joints in the lower limbs, such as the ankle or knee, may prevent the subject putting his foot firmly on the ground. Acute ankle involvement may prevent the subject forcibly plantar flexing the foot at the end of the stance phase of walking, and high pressures will therefore not develop under the forefoot. If there is acute involvement of any or all of the MT-P joints, the subject will adjust his gait so as to protect these sites. When there is MT-P joint subluxation, such that the metatarsal head is exposed to direct pressure on the sole of the foot, then high pressures may be expected at this site. On the other hand, if this lesion is painful, then the gait may be adjusted to protect this area. The pressures in the forefoot may lead to deformities in rheumatoid arthritis and these changes in themselves lead to alterations in the distribution of pressures.
These pressures were recorded when walking barefoot. Shoes are designed so as to fit comfortably around the foot and will have the effect of redistributing pressures. We were able to make only limited measurements in subjects wearing shoes, but they did suggest that there was a substantial reduction in these values at the pressure points and that the peak pressures may well be halved in comfortable footwear.

Summary
A technique is described for measuring the pressures under the different parts of the foot during walking. The characteristic distribution of pressures under the normal forefoot is described. A wide variety of abnormalities were found in feet involved by rheumatoid disease.

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