Forefoot Plantar Pressures in Rheumatoid Arthritis

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We sought to investigate the magnitude and duration of peak forefoot plantar pressures in rheumatoid arthritis. The spatial and temporal characteristics of forefoot plantar pressures were measured in 25 patients with a positive diagnosis of rheumatoid arthritis of 5 to 10 years' duration (mean, 8 years) and a comparison group using a platform-based pressure-measurement system. There were no significant differences between groups in the magnitude of peak plantar pressure in the forefoot region. Significant differences were, however, noted for temporal aspects of foot-pressure measurement. The duration of loading over sensors detecting peak plantar pressure was significantly longer in the rheumatoid arthritis group. In addition, the rheumatoid arthritis group demonstrated significantly greater force–time integrals. Significant increases in the temporal parameters of plantar pressure distribution, rather than those of amplitude, may be characteristic of the rheumatoid foot. (J Am Podiatr Med Assoc 94(3): 255-260, 2004)

The increasing use of foot-pressure measurement technology has given a new perspective to foot function in a variety of clinical applications.[1] For example, in the diabetes literature, researchers[2, 3] have identified high-pressure areas in the neuropathic foot as a precursor to ulceration. The insensate foot may be more susceptible to damage due to repetitive loading during gait, particularly where limited joint motion or bony prominences occur.[4, 5] The new understanding provided by foot-pressure measurement has enabled preventive care to be instituted early in the disease process. However, in rheumatology there are few articles demonstrating the clinical benefit of foot-pressure measurement in terms of instituting early foot care.

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In the rheumatoid foot, typical clinical features commonly observed include a valgus deformity of the rearfoot, flattened medial longitudinal arch, subluxated and prominent metatarsal heads, hallux valgus, and lesser-toe deformities, such as clawed or retracted toes.[6] In addition, numerous extra-articular features, including edema, bursitis, rheumatoid nodules, and plantar and digital calluses, are not uncommon.[7] It is well documented that the presence of foot deformities along with pain and inflammation may cause antalgic gait patterns.[8, 9] The gait alterations noted in rheumatoid patients include decreased cadence and prolonged double-limb support along with delayed heel rise.[10-12] Fortunately, owing to the presence of protective sensation, rheumatoid patients rarely develop the plantar ulcers seen in the diabetic foot.[4, 13] Given the deformities commonly seen in the rheumatoid foot, most foot-pressure studies have predominantly focused on the spatial aspects of foot-pressure measurement, eg, the magnitude and anatomical location of plantar pressures.[14-17] However, in view of the changes seen in gait patterns in individuals with rheumatoid arthritis, some authors[18-20] have suggested that the temporal parameters (eg, the duration of plantar pressure during gait) may be more important in the etiology of tissue pathology than the spatial parameters.

This study used foot-pressure measurements to investigate temporal and spatial aspects of forefoot plantar pressures in individuals with a defined duration of rheumatoid arthritis.

Methods

Patient Selection

Thirty-seven consecutive patients were recruited from the rheumatology outpatient clinics of St Albans City Hospital in St Albans, England. All of the patients had a positive diagnosis of rheumatoid arthritis, as determined by the consultant rheumatologist, and were taking part in the Early Rheumatoid Arthritis Study.[21] The inclusion criteria were a positive diagnosis of rheumatoid arthritis of 5 to 10 years' duration and an age of 18 to 70 years. The exclusion criteria were quite extensive. Individuals younger than 18 years were excluded because children with juvenile idiopathic arthritis experience growth alterations. Furthermore, in juvenile idiopathic arthritis, the synovitis rapidly leads to joint stiffness and fixation if not mobilized, and a fixed foot position can occur.[22] Individuals older than 70 years were excluded owing to the increased incidence of osteoarthritis in this age group. Individuals with a concomitant systemic disease or impaired neurologic function were excluded, as the results of a study by Chen et al[23] indicated that there may be a change in plantar pressure distribution with a changing sensory condition. Patients who had undergone a major surgical intervention, such as metatarsal head resection, were excluded. Patients who had undergone minor procedures, eg, single digital arthroplasty, were accepted. Other factors that may affect plantar pressure distribution, such as congenital defects and recent abrupt trauma (ie, within 3 months), were also grounds for exclusion. The final exclusion group consisted of patients who could not comply with the study protocol, which included individuals who could not walk 4 m on five separate occasions owing to the severity of their disability.

To discount variables due to age and gender, a comparison group was recruited from the staff of West Hertfordshire National Health Service Trust in St Albans and patients' relatives; these subjects were identified by the podiatry department's patient database. The inclusion criteria for the comparison group were an age of 18 to 70 years and no positive diagnosis of an inflammatory arthropathy. The exclusion criteria were the same as those for the rheumatoid arthritis group.

Twelve patients were subsequently excluded because they either met one or more of the exclusion criteria or could not complete the study protocol. Thus plantar pressure measurements were recorded for 25 patients with rheumatoid arthritis and 25 individuals in a comparison group.

Ethical Considerations

Ethical approval was granted for this project from West Hertfordshire Health Authority and St Albans and Hemel Hempstead National Health Service Trust local research ethics committees. Written informed consent was obtained from all participants.

Equipment

Plantar pressures were recorded barefoot using a midgait approach on a Musgrave Footprint system (Musgrave Systems Ltd, Llangollen, North Wales) interfaced with a laptop computer together with Winfoot data-acquisition software (version 1.0.15, 1998; Musgrave Systems Ltd). The Musgrave Footprint is a platform system incorporating 2,048 discrete sensors using force-sensitive resistor technology. Each sensor covered an area of 5 mm^2 with a sampling frequency of 56 Hz. Pilot studies indicated that recording of consecutive footsteps using the Musgrave Footprint two-plate system adversely affected balance, particularly in rheumatoid patients, because even with both plates side by side (though offset to allow for differences in step length), the active pressure-measuring area was wider than the natural base of gait of some individuals. Regard for the health and safety of participants necessitated that recordings be taken from the right foot only.

Data Collection

All participants were given an acclimatization period to ensure that they could step onto the pressure plate accurately without altering their natural stride pattern and while looking straight ahead. Each measurement was taken using a midgait (fourth step) approach. Participants were required to continue walking after stepping on the pressure plate for at least four steps, and they walked at a self-selected pace, with no attempt made to standardize walking speed. Five footprints were taken from each participant, as results of pilot studies suggested that this method captured the maximum variation in magnitude and duration of plantar pressures from individuals. In pilot studies, recording more than five footprints did not reveal additional data and led to fatigue in some patients with rheumatoid arthritis. However, footprints produced when a participant was noted to have hesitated were discarded, and that trial was repeated.

Data Processing and Statistical Analysis

The system software generates the magnitude and duration of plantar pressure variables over the entire foot. A standardized division mask[20] was used for data interpretation. This mask divides the foot into six regions (distal medial and lateral, middle medial and lateral, and proximal medial and lateral) using the long plantar angle as a basis. The distal medial and lateral regions were used to define the forefoot in this study, and values found in these regions were exported into an Excel spreadsheet (Microsoft Corp, Redmond, Washington).

The peak pressure value is determined by the highest pressure measured by a single sensor. The duration of loading of this sensor was also measured. However, considering that these variables were measured over a single sensor, it could be argued that this is not representative of the foot as a whole. Therefore, the force–time integral was selected to study the entire foot rather than the forefoot alone. This variable was selected because the Musgrave Footprint system, like most other plantar pressure–measurement systems, measures vertical force and derives the pressure measurement using the following equation: pressure = force/area. In addition, anatomical landmarks cannot be accurately and repeatedly located for a series of footsteps using plantar pressure–measurement patterns alone.

Baseline data were processed using a statistical software package (SPSS version 4; SPSS Science, Chicago, Illinois) and were shown to be normally distributed using the Kolmogorov-Smirnov test. Differences between peak plantar pressure and the duration of pressure between rheumatoid patients and comparison subjects were determined using the unpaired two-tailed *t*-test (assuming unequal variance).

Results

The 25 rheumatoid patients (4 men and 21 women) had a mean disease duration of 8 years (range, 5 to 10 years) and a mean ± SD age of 55 ± 11.8 years (range, 28 to 70 years). The comparison group (3 men and 22 women) had a mean ± SD age of 49 ± 8.56 years (range, 28 to 66 years). No significant differences were noted in the magnitude of the peak plantar pressure value in the forefoot between the two groups. The mean ± SD peak plantar pressure value for the rheumatoid group was 734 ± 147 kPa (range, 423 to 1,168 kPa) and for the comparison group was 780 ± 139 kPa (range, 337 to 1,616 kPa). Figure 1 shows typical three-dimensional peak plantar pressure diagrams for the rheumatoid and comparison groups.

Significant differences were noted in the temporal aspects of foot-pressure measurement. The duration of pressure over the sensor measuring the peak pressure value was significantly longer in the rheumatoid group ($P < .001$). For rheumatoid patients, the mean ± SD duration of pressure over the sensor measuring the peak pressure value was 734 ± 68 N·ms (range, 324 to 1,170 N·ms), whereas for the comparison group a mean ± SD of 624 ± 63 N·ms (range, 180 to 990 N·ms) was noted.

Rheumatoid patients also demonstrated significantly longer force–time integrals than comparison subjects ($P < .001$). The mean force–time integral seen in rheumatoid patients was 521 N·ms (range, 300 to 884 N·ms). In the comparison group, a lower mean force–time integral (413 N·ms) was found, together with a much wider range of values for the force–time integral (131 to 1,017 N·ms). In typical force–time curves, comparison subjects generally demonstrate a double-peak curve, whereas a flattened, lengthened curve is typically seen in rheumatoid patients (Fig. 2).

Discussion

The general goals of management of complications associated with rheumatoid arthritis are to reduce pain and joint inflammation and to alter the course of the disease by decreasing the progression of joint damage.[24] Cornerstone podiatric medical practices in the management of foot problems associated with rheumatoid arthritis include the removal of painful skin calluses and the use of foot orthoses and prescribed footwear. However, the efficacy of these interventions has been poorly addressed in the literature. Indeed, Woodburn and Helliwell[25] highlighted the lack of robust evidence in the literature to support these practices. Studies[14, 26, 27] that have attempted to provide measures for these cornerstone practices tended to focus on the use of peak plantar pressure readings. However, the results of this study indicate significant differences in the temporal aspects of foot-pressure measurement in individuals with rheu-

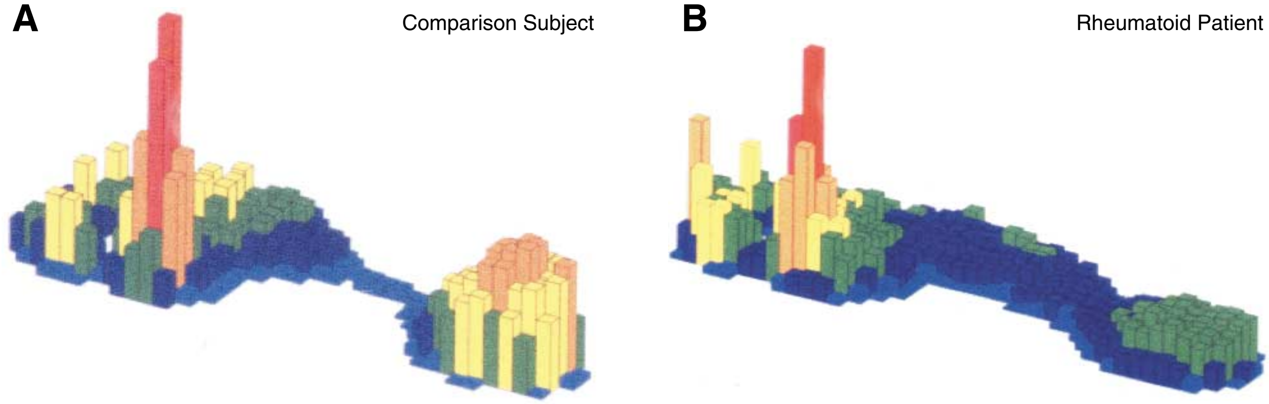

Figure 1. Typical peak pressure plots for comparison (A) and rheumatoid (B) participants.

matoid arthritis. Therefore, spatial aspects of foot-pressure measurement alone may not be the most appropriate outcome measure for predicting tissue damage in the rheumatoid patient.

The results of this study suggest that temporal parameters may be more appropriate outcome measures. It should be noted that original work focusing on gait changes in patients with rheumatoid arthritis recorded slower cadence and velocity, along with an increase in the duration of the double-support phase.[9-12] It has been suggested that the changes seen in the gait of patients with rheumatoid arthritis are partly a pain-avoidance strategy.[8, 9] This study demonstrated increased temporal parameters of forefoot plantar pressures. It is possible that these changes could be explained by patients having a slower gait. However, the Musgrave Footprint system, being a pressure-plate system, does not measure the cadence or velocity of the patient's gait cycle. Measuring the contralateral limb using a second Musgrave Footprint plate was not possible because the patient's balance was adversely affected. Furthermore, as patients walked at a self-selected speed, temporal parameters of gait would have to be calculated for each of the five trials. To date, there is little evidence of any research that has attempted to associate longer temporal plantar pressures with the changes in gait seen in patients with rheumatoid arthritis. We recommend further study in this field.

If pain avoidance is a reason for the changes in the temporal elements of gait, the longer force–time integrals and increased loading time of the sensor measuring peak pressure would not seem to be consistent with reducing pain. Rather, given the pathogenesis of the rheumatoid foot, the possibility of further tissue damage may be enhanced. It may be more likely that changes in plantar pressure can be explained by other factors. Keenan et al[12] noted symmetrical weakness in the gastrocnemius and soleus muscles of patients with rheumatoid arthritis, reducing the propulsion phase of gait. In addition, Wollheim[28] reported that the ankle is involved in 30% to 50% of cases, and this may further impair the patient's mobility. These factors may help explain the significantly longer temporal parameters noted in this study.

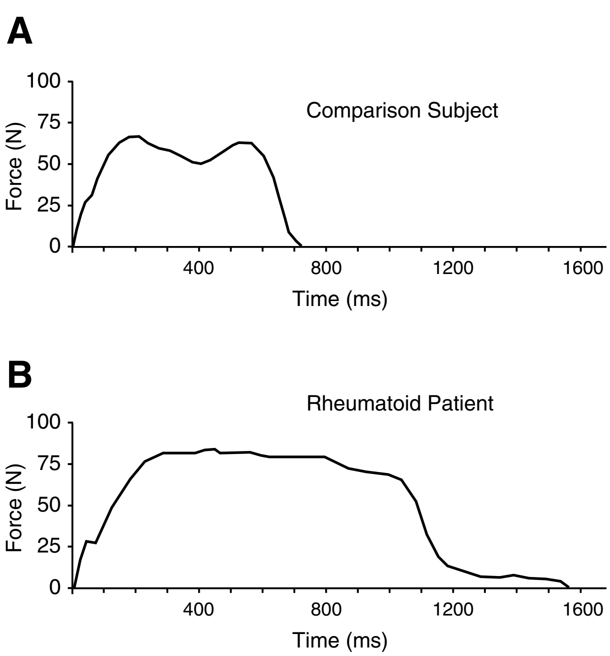

Figure 2. Typical force–time curves for comparison (A) and rheumatoid (B) participants.

The results of the present study indicate that peak forefoot plantar pressures in individuals with established rheumatoid arthritis are not significantly higher than those of a comparison group. However, the significantly increased duration of plantar pressures in this group of patients has the potential to cause tissue damage. In particular, this study investigated patients with rheumatoid arthritis of 5 to 10 years' duration. As indicated previously in this article, this patient group often has joint deformities affecting the foot, which may have lost the protection provided by subcutaneous tissue.[29] In addition, there is some evidence suggesting that the degree of erosion of the metatarsal heads together with the distal migration of fibro-fatty padding seen in rheumatoid arthritis may be associated with high plantar pressure readings.[11] Studies of peak pressures under the forefoot have been inconclusive in finding associations with lower plantar tissue thickness.[30]

In contrast to previous works,[8, 14, 18, 31] this study did not demonstrate significant differences in peak forefoot plantar pressures in patients with established rheumatoid arthritis compared with healthy individuals. However, the results of this study indicate that there are significant increases in the temporal characteristics of forefoot plantar pressure variables in rheumatoid patients. It is possible, therefore, that temporal parameters may be better predictors of change (or more appropriate outcome measures for orthotic intervention) in the rheumatoid foot than peak plantar pressures. The argument for an altered approach to the choice of outcome measure in foot-pressure measurement is clouded, however. There are many different methodologic approaches to foot-pressure measurement. Early studies, for example, report plantar pressure in non-SI (Système International) units (eg, percentage of body weight or pounds per square inch).[31, 32] Further difficulties are also encountered in comparing different foot-pressure measurement systems. For example, Woodburn and Helliwell[14] used an in-shoe system (F-Scan; Tekscan, Boston, Massachusetts) and reported higher plantar foot pressures in rheumatoid patients compared with healthy individuals. The present study used a force platform collecting barefoot data. This would seem to point to the need for the increased use of internationally recognized standard protocols[20] to allow for better inter-study comparisons of foot-pressure measurement findings.

Conclusion

The results of this study indicate that significant increases in the temporal parameters of plantar pressure distribution, rather than those of amplitude, are more characteristic of the rheumatoid foot. Thus temporal and spatial parameters should be incorporated when using plantar pressure measurement in the evaluation of podiatric medical interventions in the rheumatoid foot.

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