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# Radiologic Patterning of Hallux Deformity in Rheumatoid Arthritis and Its Relationship to Flatfoot

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ABSTRACT

Hallux deformities other than hallux valgus, especially those in the sagittal plane, have not yet been elucidated in the feet of patients with rheumatoid arthritis. The objectives of the present study were to classify rheumatoid arthritis hallux deformity in both the horizontal and the sagittal planes and investigate its relationship with flatfoot. Using a cross-sectional study design, we assessed patients with rheumatoid arthritis (527 feet in 274 patients) using radiographs and classified the deformity patterns of the great toes using cluster analysis. Of the 274 patients, the range of motion in the metatarsophalangeal joint was clinically investigated in 44 (16.1%) patients. The great toes could be divided into 5 clusters according to the characteristic configuration as follows: cluster I (normal type), cluster II (hallux valgus type), cluster III (boutonniere type), cluster IV (boutonniere with hallux valgus type), and cluster V (swan-neck type). Radiographic measurements revealed the characteristic deformities of each cluster, including splayed foot for cluster II; flat foot, metatarsal primus elevatus, and plantar displacement of the proximal phalanx for cluster III; and a mixture of these characteristics for cluster IV. Plantar displacement of the proximal phalanx, which was a specific characteristic of the boutonniere deformity, correlated significantly with the decreased dorsiflexion in the metatarsophalangeal joint. Our classification method revealed the relationship of hallux deformity in the sagittal plane to flatfoot and also demonstrated the usefulness of measuring basal phalanx displacement in predicting the range of motion of the metatarsophalangeal joint.



Rheumatoid arthritis (RA) is a systemic autoimmune disease characterized by inflammation of the synovial membranes within the joints. RA first develops in the foot and ankle region in 20% of patients (1,2). Foot and ankle involvement increases with the duration of the disease process, and >90% of patients with RA have foot and ankle symptoms during the course of their disease (2,3). Foot deformities have been increasingly receiving attention because it has become clinically evident in recent years that they have a severe negative impact on the function and quality of life in patients with RA (4–7). To construct appropriate treatment strategies, a thorough knowledge of the pathogenesis of the deformities and understanding of their mutual relationship are necessary. However, it can be difficult to acquire this knowledge owing to the variety of deformities and simultaneous multiple involvements.

Among the deformities in the rheumatoid foot, hallux valgus has been recognized as the most common feature and flatfoot as the second (2,6). However, even the relationship between these deformities remains controversial (8,9). One of the common problems in previous studies has been that deformities of the great toe were assessed as a form of metatarsus primus varus, which shows a deformity in only 1 dimension of a horizontal plane. Clinically, deformity of the great toe will have a wide range of variations and will show mixed features (10), which are indefinable in the horizontal plane alone. However, no previous studies have evaluated rheumatoid hallux deformities quantitatively in the sagittal plane. To create appropriate treatment strategies for composite hallux deformity in the rheumatoid foot, it would be beneficial to understand the pattern of deformity in multiple dimensions and its relationship to flatfoot.

Cluster analysis is a data mining procedure used to identify groupings of individuals according to a set of measurements or observations

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such that the objects in the same group are more similar to each other than to those in the other groups. It is known as an extremely useful taxonomy in a wide variety of research areas, in particular, in the field of medicine by clustering diseases, cures for diseases, and symptoms of diseases (11). Cluster analysis has also been applied in orthopedics for classifying the deformities or bone destructive patterns such as scoliosis, rheumatoid foot, and knee osteoarthritis (12–14).

In the present study, we investigated patients with RA in our hospital in a cross-sectional design using some series of standing radiographs and classified the deformity in the horizontal and sagittal planes using cluster analysis. Moreover, we analyzed the association between each classified deformity pattern and flatfoot.

## Patients and Methods

### Patients

The present research was a cross-sectional study of 307 consecutive patients with RA who had consulted the Department of Rheumatology at Yugawara Hospital (Kanagawa, Japan) between March 2009 and May 2011. All patients provided written informed consent, and the ethical committees of our institution approved the study. The cases were consecutive, and 33 (10.8%) patients with a history of previous foot surgery were excluded. All the patients met the required American College of Rheumatology classification criteria for RA (15). The patients included 30 (10.95%) males and 244 (89.1%) females, with a mean age of 64.4 (range 26 to 89) years. The mean duration of disease was 14.4 (range 0.5 to 46.1) years. Of the 274 patients evaluated radiographically, the range of motion (ROM) in the metatarsophalangeal (MTP) joint of the great toe was also assessed clinically in 44 (16.1%) consecutive patients who had consulted our clinic during a specific period. The sample size required to have a significant result of correlation coefficient with a 95% confidence level was estimated to be 24 for a moderate correlation with a coefficient value of 0.4. We completed the surveillance in 1 week because we could evaluate 44 patients (86 feet), satisfying the required sample size. To obtain radiographic measurements for patients without RA, the control group was recruited from among patients who had consulted our hospital for reasons other than forefoot deformity and who had standing lateral and anteroposterior radiographs of the foot available. Patients were excluded if they had ≥1 of the following: fracture, forefoot deformity in appearance, connective tissue disease, or a neurologic disorder. Finally, 50 patients (55 feet), including 7 (14%) males and 43 (86%) females, with a mean age of 52.7 (range 29 to 67) years were recruited for the control group. A comparison of the demographic data between the patients with RA and the control group is given in Table 1.

### Radiographic Evaluations

The following angles were evaluated from the standing bilateral anteroposterior radiographs:

1. *Hallux valgus angle:* The angle between the longitudinal axis of the first metatarsal bone and that of the proximal phalanx (16)
2. *1-2 Intermetatarsal (M1M2) angle:* The intermetatarsal angle between the first and second metatarsals (16)
3. *1-5 Intermetatarsal angle (M1M5) angle:* The intermetatarsal angle between the first and fifth metatarsals (17) (Fig. 1*A*)

The following angles were evaluated from the standing lateral radiographs:

1. *Calcaneal pitch:* The angle between the line drawn from the plantar surface of the calcaneus to the inferior border of the calcaneocuboid joint and the line drawn from the plantar surface of the calcaneus to the inferior surface of the fifth metatarsal head (17)
2. *Talar–first metatarsal angle:* The angle between the long axis of the talus and that of the first metatarsal (17)
3. *First metatarsal (MT-I) declination angle:* The angle between the longitudinal axis of the first metatarsal and the ground (18)
4. *MTP joint dorsiflexion angle:* The angle between the longitudinal axis of the first metatarsal and that of the proximal phalanx (18)
5. *Interphalangeal (IP) joint dorsiflexion angle:* The angle between the longitudinal axis of the first proximal phalanx and that of the distal phalanx (Fig. 1*B* and *C*)

**Table 1**
Comparison of demographic data from rheumatoid arthritis (n = 274) and control (n = 50) groups

| Variable | RA Group (n = 274) | Control Group (n = 50) | *p* Value |
|---|---|---|---|
| Sex | | | .146 |
| Male | 30 | 7 | |
| Female | 244 | 43 | |
| Age (y) | | | <.001 |
| Mean | 64.4 | 52.7 | |
| Range | 26 to 89 | 29 to 67 | |
| Disease duration (y) | | NA | NA |
| Mean | 14.4 | | |
| Range | 0.5 to 46.1 | | |

Abbreviations: NA, not applicable; RA, rheumatoid arthritis.

Longitudinal axes bisecting the shafts of the metatarsals and phalanges were drawn by connecting 2 reference points set on the bone. The metatarsal reference points in the anteroposterior radiographs were placed 1 to 2 cm proximal to the distal articular surface and 1 to 2 cm distal to the proximal articular surface (18). The proximal metatarsal reference points in the lateral radiographs were placed 1 to 2 cm distal to the proximal articular surface and the distal points were placed on the center of the approximate circle fit in the metatarsal head. The phalangeal reference points in the anteroposterior and lateral radiographs were placed 0.5 to 1 cm distal to the proximal articular surface and 0.5 to 1 cm proximal to the distal articular surface or the tip of distal phalanx (18). Metatarsus primus elevatus was measured using the method described by Bouaicha et al (18) (Fig. 1). To measure the displacement of the proximal phalanx against the first metatarsal, we defined a new measurement method. The longitudinal axis of the first metatarsal and that of the proximal phalanx were drawn. Two intersection points of these 2 lines with the approximate circle fit in the metatarsal head were marked. The angle between the 2 lines connecting the center of the circle in the metatarsal head and these 2 intersecting points was measured as the subluxation index, which was positive when the proximal phalanx was dislocated in the plantar direction against the metatarsal head (Fig. 1*D*). All the radiographic evaluations were digitally measured using PACS software (SYNAPSE; Fujifilm Medical Co., Tokyo, Japan). To remove the influence of interobserver variability, all the measurements were taken by an independent board-certified member of the Japanese Orthopedic Association who was not otherwise involved in the study. To determine the precision of the measurements, the intraclass correlation coefficient and the standard error of the mean were calculated from the evaluation data collected from 35 randomly selected films graded by the observer 2 times at an interval of ≥6 months with blinding of patient identity.

### ROM Measurement

The ROM in the MTP joint of the great toe was measured in the non-weightbearing foot with the ankle in a neutral position. Each of the dorsiflexion and plantarflexion angles was measured using a goniometer as the angle between the axes of the first metatarsal and the basal phalanx.

### Statistical Analysis

All data are reported as the mean ± standard error, except for the primary radiographic measurements of the subjects, which are reported as the mean ± standard deviation (Table 2). *p* Values of ≤ .05 were defined as significantly different. We performed a cluster-based analysis to reveal the pattern of deformity in all the evaluated feet. Of the many different clustering methods, we chose the k-means method, because this model is well established and the most widely used in published studies (19). To determine statistically significant differences for the comparison of all radiologic measurements among the clusters, we used 1-way analysis of variance because 1 factor (independent variable) was analyzed among >2 groups. The Tukey-Kramer test was used as a post hoc test because the sample sizes were unequal among the clusters. Statistical analyses of the data were performed using the statistical software JMP, version 9 (SAS Institute Inc., Cary, NC).

## Results

A total of 21 sets of radiographs of 15 patients were inadequate for interpretation because of over- or underexposure, leaving 527 sets of radiographs for our analysis. The results of the radiographic measurements for 527 feet in the patients with RA and 55 feet in the control group are listed in Table 2. The intraclass correlation coefficients and standard error of the mean calculated from the randomly selected 35 feet indicated good reproducibility and validity of the measurements (Table 2). To classify the hallux deformity in terms of both transverse and sagittal planes, a cluster analysis was performed using the following measurements as variables: hallux valgus angle, subluxation index, MTP joint dorsiflexion angle, and IP joint dorsiflexion angle. These 4 variables were selected because they are the minimum requirements to outline the hallux configuration. Cluster analysis revealed that the 527 feet could be divided into 5 clusters, each with a specific characteristic deformity, as follows: cluster I (normal type, 259 feet; 49.2%),