FOOT & ANKLE INTERNATIONAL


# Influence of Foot Characteristics on the Site of Lower Limb Osteoarthritis

Kathleen Anne Reilly, M.Sc.[1]; Karen Louise Barker, Ph.D.[1]; Delva Shamley, Ph.D.[2]; Susan Sandall, Chir.[3]
[1,2]Oxford, United Kingdom; [3]Reading, United Kingdom

## ABSTRACT

***Background:*** **Foot structure and range of motion have been linked to lower limb musculoskeletal injuries in sports medicine,[11,14,41] and recently there have been attempts to establish a connection between the foot and lower limb osteoarthritis (OA).[19,13] Considering the fact that OA of the knee and hip are the most important causes of pain and disability in older people,[12,25] it is surprising that there has been no research comparing the foot types of those with knee OA and those with hip OA. To evaluate an apparent difference in the feet and gaits of patients with hip OA and medial compartment OA of the knee that was noted during routine clinical assessment, a prospective observation study was undertaken.** ***Methods:*** **The study included patients with OA either of the hip or the medial compartment of the knee and a control group of healthy subjects. There were 60 in each group determined by sample size calculation. The groups were matched for age and gender. Dorsiflexion and plantarflexion of the ankle, calcaneal angle, and navicular height in both sitting and standing were measured. Results were analyzed by ANOVA and linear regression analysis.** ***Results:*** **There were significant differences among all three groups, particularly in ankle dorsiflexion ($p < 0.001$) and calcaneal angle ($p < 0.001$).** ***Conclusions:*** **Differences in foot type between patients with OA of hip and knee were confirmed. These two groups also were different from the control group of healthy subjects. The lack of ankle dorsiflexion and high arches of patients with OA of the hip contrasted with the ample dorsiflexion and flatfeet of patients with OA of the knee.**

[1]Physiotherapy Research Unit, Nuffield Orthopaedic Centre NHS Trust, Oxford, United Kingdom
[2]Institute of Health and Social Care, Oxford Brookes University, Oxford, United Kingdom
[3]Podiatry, Brightwell Clinic, Reading, United Kingdom

Corresponding Author:
Kathleen Anne Reilly, M.Sc.
Physiotherapy Research Unit
Nuffield Orthopaedic Centre NHS Trust
Windmill Road, Headington
Oxford
United Kingdom
E-mail: kathleen.reilly@noc.anglox.nhs.uk
For information concerning prices and availability of reprints, call 410-494-4994 X226
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## INTRODUCTION

The effects of foot structure on lower limb musculoskeletal injuries have been frequently reported.[11,14,41] Much of this work focuses on the effects on younger people, particularly athletes, or on older active runners. A study of U.S. Marine recruits found that high-arched or supinated feet were more susceptible to stress fractures than flatter feet, because they were less able to absorb shock.[22] In the same study, flat or pronated feet were found to be associated with shin splints or knee pain. Other studies have demonstrated a relationship between foot types and athletic problems such as patellar pain and lower extremity overuse injuries.[33,39] It has been suggested that high-arched feet are inflexible,[15] while flatfeet are more mobile and susceptible to high degrees of pronation.[27,40] Athletes with both pronated and supinated feet have been shown to have significantly more knee pain than a neutral group.[9]

The orthopaedic literature also has considered the influence of the foot on lower limb osteoarthritis (OA).[13,19] A study that compared patients with OA of the knee and age-matched healthy subjects[4] found that patients with OA of the knee had an increased incidence of leg-length discrepancy and a more inverted subtalar joint neutral position on the affected side. The foot is now more often considered when the lower limb is being examined. Current measurement standards for preoperative planning and evaluation of results using radiographs traditionally apply ground reaction force to the ankle. It has been demonstrated that including the foot in these measurements alters the mechanical alignment of the lower limb.[18]

The first published paper to look at the effects of different foot structure and range of motion in a healthy nonathletic and skeletally mature population[20] did not find that flatfeet were a cause of disability. The population studied were workers in a grocery chain store who were between the ages of 18 and 65 years. The study did, however, suggest that those individuals who had disabilities might not have remained in this kind of employment. An interesting finding was that in the normal population the percentage of both flat and high-arched feet was relatively low compared with the average arch structure.

In the literature of sports medicine, there is a long history of the use of orthoses in the treatment of lower limb disorders,[8,23,30,44] and recently it has been suggested that orthoses that alter hindfoot characteristics might prove useful in the conservative management of OA of the lower limb. Both heel lifting as a conservative therapy for OA of the hip[31] and lateral wedged insoles for OA of the medial compartment of the knee[42] have been proposed.

Considering the fact that OA of the knee and hip is the most important cause of pain and disability in older people,[12,25] it is surprising that there has been no research comparing the foot types of these two groups. Therefore, when apparent differences in the feet and gaits of patients with OA of the hip and medial compartment of the knee were noted during routine preoperative clinical assessment for hip and knee arthroplasty, a pilot study was conducted. This supported the hypothesis that these patients appeared to represent the two ends of the continuum of normal range from high-arched to flatfeet. As has been demonstrated,[20] this is not typical of the general population. During the pilot study the differences in range of ankle dorsiflexion between the two patient groups was noted. Subsequently, a prospective observational study was undertaken to examine ankle and hindfoot characteristics of patients with OA of the hip (HOA), patients with OA of the medial compartment of the knee (KOA) and a control group (C) of healthy subjects in an effort to determine whether any significant differences in hindfoot characteristics existed among these three groups.

## MATERIALS AND METHODS

### Setting

The study was carried out in an orthopaedic hospital where usual clinical practice includes a visit to a pre-admission clinic 10 to 14 days before surgery. At this clinic, physiotherapists routinely examine affected joints, as well as the joints above and below, to plan postoperative rehabilitation.[5] The physiotherapists examine patients standing and walking to record any leg-length discrepancy, valgus or varus alignment of the knee, and gait patterns. Differences in foot type are more easily observed during standing and walking.

### Participants

At the preadmission clinic, measurements were taken of consecutive patients before hip (HOA group) or unicompartmental knee arthroplasty (KOA group). Age-matched volunteers (C) were recruited and measured. There were 60 subjects in each of the three categories. Any patients or volunteers with a history of previous trauma or operation on the affected limb or neurologic problems were excluded from the study. Measurements were taken by two experienced research physiotherapists. Institutional review board approval was obtained for the study.

### Procedure

Four measurements were taken. These measurements were selected with advice from the fourth author who is a podiatrist who has specialized in biomechanics and were previously tested for intertester reliability at the pilot stage.

#### *Ankle dorsiflexion and plantarflexion*

Ankle dorsiflexion and plantarflexion were measured using a long-arm universal goniometer. This method has good reported repeatability.[10] The patient was seated and the knee flexed by the physiotherapist to 45 degrees to allow flexibility of the Achilles tendon. The patient was then asked to hold the knee position and to dorsiflex then plantarflex the ankle. The measurement taken was of ankle movement. A line was drawn horizontally along the lower border of the shaft of the fifth metatarsal. A mark was made on the lateral side of the leg halfway between the anterior and posterior aspects of the tibial plateau. A second mark was made halfway between the anterior and posterior aspects of the ankle at the level of the malleoli. A line was drawn to connect these two marks. The arms of the goniometer were placed on these lines and the fulcrum on a dot drawn approximately on the center of the lateral malleolus.

#### *Standing calcaneal inversion/eversion measurement*

The calcaneal angle relative to the lower leg has been suggested to provide information about motion at the subtalar joint.[21] For this study, it was decided to measure the angle of the calcaneus to the floor, weightbearing in relaxed stance, because it was in this position that the differences between patients were observed. It has been shown that there is significant correlation between the commonly used static rearfoot alignment and frontal plane radiographic parameters.[24] It also is the most common method of hindfoot analysis.[18]

To achieve as normal a standing position as possible, the patient was asked to march on the spot for four steps and then relax. A plumb line was dropped bisecting the lower limb and marked three times equidistantly from the midgastrocnemius region to floor. A line joined the marks. The physiotherapist then sat behind the opposite foot to accommodate the medial curve of the calcaneus and drew a line bisecting the calcaneus. The angle between the bisected calcaneus and a line perpendicular to the floor from a point superior to the height of the medial malleolus was measured.

#### *Navicular height*

Measurement of the highest point of the medial longitudinal arch (MLA) in the sagittal plane is one of the simplest methods of providing a clinician with quantifiable information regarding static foot structure.[35] The prominent navicular

**Table 1:** One Way Analysis of Variance (ANOVA)

| | Group | Mean Values | Standard Deviation | F-value | Statistical Significance |
|---|---|---|---|---|---|
| Plantar flexion | HOA | 51.22 | 11.70 | | |
| (degrees) | KOA | 50.72 | 11.49 | .239 | 0.788 |
| | C | 52.13 | 10.94 | | |
| Dorsiflexion | HOA | 2.62 | 4.86 | | |
| (degrees) | KOA | 10.07 | 4.29 | 49.284 | 0.000* |
| | C | 8.4 | 3.71 | | |
| # Calcaneal | HOA | −2.67 | 2.58 | | |
| angle (degrees) | KOA | 2.02 | 2.04 | 50.851 | 0.000* |
| | C | −.25 | 2.93 | | |
| Navicular height | HOA | 5.69 | .74 | | |
| (sitting) (cms) | KOA | 5.22 | .94 | 5.374 | 0.005* |
| | C | 5.28 | .89 | | |
| Navicular height | HOA | 5.18 | .76 | | |
| (standing) (cms) | KOA | 4.69 | .83 | 5.979 | 0.003* |
| | C | 4.73 | .98 | | |

HOA—Hip osteoarthritis patients, 31 men, 29 women, mean age 66.58 +/− 9.11 years
KOA—Knee osteoarthritis patients, 25 men, 35 women, mean age 67.80 +/− 8.09 years
C—Healthy controls, 28 men, 32 women, mean age 64.92 +/− 12.18
# Negative calcaneal angle indicates an inverted calcaneus (supinated foot)
Positive calcaneal angle indicates an everted calcaneus (pronated foot)
*Significant at $p = 0.05$.

**Table 2:** Linear Regression Analysis*

| | | Unstandardized Coefficients | | Standardized Coefficients | | |
|---|---|---|---|---|---|---|
| Model | | B | Std. Error | Beta | t | Sig. |
| 1 | (Constant) | 15.446 | 2.754 | | 5.609 | .000 |
| | gender | .851 | .720 | .079 | 1.181 | .239 |
| | age | −.060 | .035 | −.115 | −1.704 | .090 |
| | group | −2.862 | .437 | −.439 | −6.542 | .000 |

* = Dependent Variable: dorsiflexion

bone is taken to represent the highest point of the MLA. It usually is visible as the most prominent point on the inner side of the foot or it can be palpated. A ruler was used to measure the distance between this point and the supporting surface. This measurement has good reported reliability.[46]

The patient was measured seated in a chair with the knee bent to 90 degrees, and the ankle also at 90 degrees (using blocks if necessary). The examiner marked a horizontal line on the navicular tuberosity on each foot. With each foot resting on the ground or block, the height of the mark was measured (navicular height in sitting). Then the patient stood up, marched on the spot for four steps and was asked to adopt a relaxed standing position, and the height of the mark from the ground was measured (navicular height in standing).[34]

#### Statistical Analysis

The primary outcome measure was ankle dorsiflexion. Boone et al[3] reported that, based on normal values for people between the ages of 61 and 69 years, 4 degrees is a clinically significant difference ($\delta$).

Using normal values, the standard deviation (S) used was based on 4.6

Altman's nomogram[1] was used. A sample size calculation indicated that for 90% power and a $p$ value of 0.05, 56 feet in each group would be needed to detect differences of 4 degrees in ankle dorsiflexion (Std Diff $= \delta/s = 4/4.6 = 0.86$). Actual numbers were 60 in each group.

A one-way analysis of variance (ANOVA) was used to analyze the data. Regression also was used to analyze inter-group differences while controlling for age and gender.

## RESULTS

The descriptive details of the patients are detailed in Table 1. A negative calcaneal angle indicates an inverted calcaneus (supinated foot), and a positive angle indicates an everted calcaneus (pronated foot). There were statistically significant differences among HOA (hip group), KOA (knee group) and C (controls) for measures of ankle dorsiflexion, standing calcaneal inversion/eversion, and navicular height but not for plantarflexion of the ankle (Table 1). For all subjects, dorsiflexion measurements fell within a normal distribution curve. Mean ankle dorsiflexion in the hip group was 2.5 degrees and in the knee group 10 degrees. Linear regression analysis (Table 2) showed that there was an $R^2$ of 21.8% for ankle dorsiflexion. There were clear differences in dorsiflexion among the groups with most of the further variance being due to age which concurs with Boone et al's study.[3]

## DISCUSSION

The foot and ankle complex is multi-functional. It is one of the most dynamic structures of the skeletal system.[2] It is strong enough to support the weight of the body on ground contact but supple enough to absorb shock. It is malleable to accommodate uneven surfaces and yet also resilient to provide the "spring" in gait.[36] Pronation occurs as a result of closed kinetic chain subtalar joint rotation, which leads to a flattening of the medial arch and a loosening of the joints in the foot, which has a shock absorbing effect[37] and allows adaptation to uneven terrain.[2] Because of the tight-fitting rectangular shape of the ankle joint, the tibia also rotates as the talus pronates.[32] Re-supination then occurs, accompanying external rotation of the weightbearing limb as the body weight passes over the foot and the contralateral limb moves forward.[28] This closed kinetic chain supination results in a higher arch shape and an increased rigidity of the foot joints that allow the foot to become a lever for propulsion.[37,41,45]

This transition from supination to pronation and back again to supination occurs concurrently with closed chain dorsiflexion of the ankle, which is followed by plantarflexion as the contralateral limb moves forward. Disruption of any component of the gait cycle can result in a perturbance in the normal free flow of gait.

Flatfeet are susceptible to high degrees of pronation.[27] When subtalar pronation persists through midstance while contralateral pelvic advancement is producing an external rotation moment on the femur, the knee is placed under significant axial torsion.[41] During walking, which is by far the most common daily activity exerting the greatest repetitive forces through the knee,[38] most of the force is exerted through the medial compartment.[17,45] Anteromedial OA of the knee has been proposed as a distinct clinical pathologic entity; the common localization of the lesions to the anteromedial quadrant of the joint suggests it is mechanically driven.[17] The anteromedial quadrant of the knee is the contact area when the leg is extended and fully weightbearing during the midstance phase of gait. This coincides with the timing of subtalar overpronation. The relationship between subtalar overpronation and flat-footed gait with medial compartment OA of the knee has not yet been explored.

Similarly, while in the literature to date there is no report of an association between a high-arched foot and OA of the hip, the area of the lesion is where weightbearing occurs from heel strike through midstance. The impulsive loads experienced at heel strike during normal level walking are associated with degeneration of the joints of the lower limb.[16] The feet of the patients with OA of the hip (HOA) had a mean dorsiflexion of 2.5 degrees, which is less than what is considered necessary for smooth normal gait.[26] This lack of dorsiflexion results in a shortened phase of pronation.[7] It has been shown that lack of pronation diminishes shock absorbency at heel strike in normal gait.[43] The inverted calcaneus observed in this group further inhibits pronation. Unlike the knee, the hip does not have the protective shock absorbency of the menisci.

During normal gait, the body passes over the foot after heel strike, through midstance to toe off. The knee joint is extended at this time. The gradual dorsiflexion that progresses through mid-stance and terminal-stance is considered most critical.[32] When dorsiflexion of the ankle is limited and the knee fully extended, body weight must pass over the extending hip joint while the pelvis is at the same time rotating through 10 degrees.[32] This may contribute to a the superolateral wear of the acetabulum identified in OA of the hip as a local mechanical factor.[29]

The biomechanics of the foot and ankle may, therefore, play a role in the biomechanics of the knee and hip at heel strike and mid-stance phases of gait.

The results of this study indicate that there is a difference in the foot characteristics of patients with end-stage OA of the hip and the medial compartment of the knee. However, there is a question whether the foot influences the site at which lower limb OA develops or whether these changes are secondary to OA and develop as compensatory mechanisms. Many patients and controls in the study were unable to state whether they had either high-arched or low-arched feet currently or whether they had changed recently. However, almost without exception, subjects cited family members, either parents, siblings, or children, with similar feet although they were not able to define the type of foot. Group HOA were the most aware: 45% stated that they had always had high arches and none could recall having flatfeet as children. In addition, a search of the literature did not reveal a report of acquired high arches except when associated with neurologic problems such Charcot-Marie-Tooth syndrome, muscular dystrophy, syphilis or other neurologic conditions. There were no subjects in the study with a diagnosis of any neurologic problem. A study that examined ankle dorsiflexion in different age groups[3] noted that ankle dorsiflexion decreased with age, which this study also demonstrated. Given the relationship of dorsiflexion and the high-arched foot to OA of the hip found in this study it could be extrapolated that age-related decreases in dorsiflexion may increase susceptibility to OA of the hip.

In Group KOA, 18% of patients stated that they had flatfeet in childhood sufficiently pronounced to require medical attention. Acquired flat foot is a recognized condition in the adult population,[43] but from a mechanical viewpoint if the varus deformity typical of medial compartment OA of the knee influenced hindfoot characteristics it would favor the development of a supinated foot position rather than a pronated one.

This study showed a measurable difference in the feet of patients who have OA of the hip and those who have OA of the medial compartment of the knee. It found a significant association ($p < 0.05$) between the lack of adequate dorsiflexion and calcaneal inversion and the presence of OA of the hip and a significant association ($p > 0.05$) between increased navicular height and OA of the hip. These characteristics are associated with a high-arched foot.

A significant association ($p > 0.05$) between a good range of dorsiflexion and calcaneal eversion and the presence of OA of the medial compartment of the knee also was shown, with a significant association ($p > 0.05$) of lower navicular height. These characteristics are associated with a flatfoot.

Ankle dorsiflexion has not been considered in previous attempts to classify foot types and to relate foot structure to foot and lower limb function.[6,22,25] The significant differences found in this study suggest that it may be relevant and because it is a relatively reliable measurement,[7] it may be worth including.

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