**Title page**

**Assessment of fore-, mid-, and rear-foot alignment and their association with knee symptoms and function in patients with knee osteoarthritis**

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**Abstract** (248 words)

**Objective:** Hallux valgus, flatfoot, and rearfoot eversion are well-known major complications of knee osteoarthritis (OA). However, there is no consensus on the association between these foot malalignments and knee symptoms or function. Thus, this study aimed to examine the association between foot alignment and knee symptoms or function in patients with knee OA.

**Methods:** Female patients aged ≥50 years with symptomatic knee OA participated in this study. Knee symptoms and function were assessed using the Knee Society Scoring System (KSS). Hallux valgus, navicular/foot ratio, and leg heel alignment were used as the forefoot, midfoot, and rearfoot alignment indices, respectively. The navicular/foot ratio was defined as the ratio of the navicular height to the total foot length. We performed multiple linear regression analysis to examine the associations between foot alignment and knee symptoms or function.

**Results:** Seventy-eight participants participated our study. KSS symptom score was significantly associated with navicular/foot ratio (Regression coefficient [β], -0.30; 95% confidence interval [CI], -109.2 to -20.5; P=0.005), knee extensor strength (β, 0.32; 95% CI, 0.02 to 0.09; P=0.004), and age (β, 0.24; 95% CI, 0.01 to 0.32; P=0.036). KSS function score was not associated with foot alignments but with knee extensor strength (β, 0.40; 95% CI, 0.10 to 0.33; P=0.001) and body mass index (β, -0.35; 95% CI, -2.82 to -0.66; P=0.002).

**Conclusions:** Knee symptoms were significantly associated with midfoot alignment in patients with medial knee OA. This suggests that lower navicular height in patients with medial knee OA may relate with the alleviation of knee symptoms.

**Key points**

- In patients with medial knee OA, midfoot alignment was significantly associated with knee symptoms in patients with medial knee OA; however, knee function was not associated with foot alignment.

- Lower navicular height in patients with medial knee OA may relate with the alleviation of knee symptoms.

**Keywords:** medial compartment knee osteoarthritis, hallux valgus, navicular height, leg heel alignment, knee society scoring system

## Introduction

Knee osteoarthritis (OA) is a chronic musculoskeletal disease that often leads to knee pain and physical dysfunction [1]. For knee OA, intra-articular injections are selected as non-surgical treatment, however curative treatment has not established [2]. Progression of knee OA increases the limitation of daily living [3-4], thus prevention of OA progression is necessary.

Many patients have medial knee OA, which is associated with knee flexion contracture, knee varus deformity, and foot deformity [5-6]. According to previous studies [6-7], patients with knee OA show compounded malalignment, including posterior pelvic tilt, a significantly lower medial longitudinal arch, and rearfoot eversion. Moreover, the prevalence of flatfoot and hallux valgus in patients with knee OA is 38.3–49.5% [8-10] and 12.5–22.6% [8, 11], respectively; thus, flatfoot and hallux valgus are major complications of knee OA [4-6]. Therefore, to determine knee function and symptoms in patients with knee OA, both knee alignment and foot alignments should be considered.

Regarding the association of foot deformity with knee symptoms and function, Gross reported that flatfoot was associated with worsening knee pain in elderly people with knee pain [12]. In contrast, according to a previous study by Iijima, there were no significant differences in the Japanese Knee Osteoarthritis Measure (JKOM) activities of daily living scores or physical function between the flatfoot and control groups [11]. Thus, previous studies have not reached a consensus on the association between foot alignment and knee symptoms and function.

Foot alignment has three components: forefoot, between the phalanx distalis and the metatarsal bone; midfoot, between the navicular, cuboid, and cuneiform bones; rearfoot, between the talus and calcaneus. Forefoot alignment is defined and assessed by the row of the hallux [13]. When the hallux row movement is restricted, the impact absorption function of the medial longitudinal arch is impaired [14-15]. Navicular drop is a typical midfoot malalignment that increases the impact on the foot during heel contact while walking, resulting in higher mechanical stress on the knee [16-17]. Excessive eversion of the subtalar joint is a rearfoot malalignment that causes lower limb and knee internal rotation. Moreover, knee soft tissue and joint cartilage are damaged [18-19]. Thus, foot alignment involves the forefoot, midfoot, and rearfoot intricately, and the effects of each alignment disorder on the knee joint have been reported [14-19]. However, to the best of our knowledge, no previous study has comprehensively assessed these three divisions of the foot and investigated the associations between foot alignments and knee symptoms or function.

This study aimed to examine the association between foot alignment and knee symptoms or function in patients with knee OA. We hypothesized that midfoot alignment, which is associated with flatfoot, would be more associated with knee symptoms and function. Clarifying these associations will provide valuable information for modifying foot alignment to improve knee symptoms and function in patients with knee OA.

## Material and Methods

### Study participants and selection

Female patients aged ≥50 years with knee OA were recruited from two orthopedic clinics in Kyoto, Japan. The inclusion criteria for knee OA were (1) a diagnosis of Kellgren-Lawrence (KL) grade ≥2, (2) symptomatic knee OA, and (3) medial femoral tibial joint OA. The definition of symptomatic knee OA was Knee Society Scoring System (KSS) symptom score of <23 [20]. The exclusion criteria were as follows: (1) lateral knee OA, rheumatoid arthritis, and knee osteonecrosis; (2) history of surgery of the lower limbs; and (3) cardiovascular or neurological disorders.

All procedures in this study were approved by the Ethics Committee of the Kyoto University Graduate School of Medicine and conducted according to the principles of the Declaration of Helsinki. All patients were informed of the aims and procedures of the study, and written informed consent was obtained from all participants before the study.

**Assessments of knee function and symptoms**

Using the KSS 2011 Japanese Edition as a self-reported assessment tool, knee function and symptoms were assessed. The reliability of the 2011 KSS for the Japanese population was demonstrated by Taniguchi [21]. Of the four sub-categories of KSS, symptom scores (0–25 points) and function scores (0–100 points) were used in this study. Higher KSS scores indicate better function and less pain in knee joints.

**The radiographic severity of knee OA**

Radiographs were taken for all participants while standing in the anteroposterior weight-bearing position with the knee in semi-flexion [22]. Osteoarthritis severity was assessed using the KL grading system by an experienced orthopedist blinded to the clinical data. The side with the most severe knee osteoarthritis was targeted. Additionally, if patients had equal radiographic severity in both knees, the targeted side was defined as the more painful knee.

**Assessments for foot alignments**

Three foot alignment indices of the targeted side were assessed in the standing position, with 50% body weight on each foot.

The hallux valgus angle was selected as the forefoot index, and the angle of intersection between the axis of the first metatarsal and that of the first proximal phalanx was measured using a goniometer [13] (Fig. 1: a).

The midfoot index, navicular/foot ratio, was defined as the ratio of the navicular height to the total foot length. Navicular height was defined as the distance from the floor to the navicular tuberosity (Fig. 1: b), and the total foot length was defined as the distance from the calcaneus to the tip of the second toe. The reliability of the navicular/foot ratio has been demonstrated in a previous study [23]. It was used to normalize individual variations in the arch structure due to variations in the total foot length.

The leg heel alignment (LHA) angle was selected as the rearfoot index, which is defined as the angle between the midline of the distal leg and calcaneus axis, measured using a goniometer [24, 25] (Fig. 1: c). Inversion was defined as positive, and eversion was defined as negative.

**Measurement of knee extensor strength**

Maximum isometric knee extensor strength (N) was measured using a dynamometer (Isoforce GT-330; OG GIKEN Co., Okayama, Japan). The participants were seated on a dynamometer with the knee joint at 60° flexion and hip joint at 90° flexion. The maximum torque (Nm) was calculated by multiplying the maximum force (N) by the lever arm (m).

**Statistical analysis**

All statistical analyses were conducted using the IBM SPSS Statistics 22 software (version 25.0; SPSS Japan Inc., Tokyo, Japan). Statistical significance was set at $p < 0.05$.

For descriptive statistics, continuous variables are expressed as mean ± standard deviation (SD), and categorical variables are expressed as numbers and percentages. Pearson's correlation analysis was conducted to confirm the association between foot alignments.

To identify whether KSS symptom scores were associated with foot alignment, we performed multiple linear regression analyses with KSS symptom scores as the dependent variable and foot alignments as independent variables. Additionally, multiple linear regression analysis was conducted with adjustment variables, including knee extensor strength, radiographic knee OA severity, age, and body mass index (BMI).

We also performed other multiple linear regression analyses conducted with the KSS function scores as the dependent variable and other variables as above.

**Results**

Of the 91 participants, 78 were included in the analysis. Thirteen participants were excluded because of lateral knee OA (n=6), history of surgery for the lower limb (n=1), asymptomatic knee OA (n=5), and missing values (n=1).

Participants' characteristics are presented in Table 1. The mean age was 73.3±7.21 years, and the mean BMI was 23.6±3.40 kg/$m^2$. Of the 78 patients with knee OA, the KL grades were as follows: grade 2, n=32; grade 3, n=24; and grade 4, n=22. The mean hallux valgus angle was 29.8±10.8 degrees, mean navicular/foot ratio was 0.16±0.02, and mean LHA angle was -1.91±4.65 degrees (eversion 1.91 degrees). Pearson's correlation coefficients are shown in Table 2. No significant correlation was found between foot alignments.

Table 3 shows the associations between KSS symptom scores, foot alignments, and other variables. Lower KSS symptom scores were significantly associated with a smaller navicular/foot ratio (regression coefficient [β], -0.30; 95% confidence interval [CI], -109.2 to -20.5; P=0.005); however, other foot alignments, such as hallux valgus and LHA angle, did not show a significant association. Additionally, knee extensor strength (β, 0.32; 95% CI, 0.02 to 0.09; P=0.004) and age (β, 0.24; 95% CI, 0.01 to 0.32; P=0.036) were significantly associated with KSS symptom scores.

Table 4 shows the results of the multiple regression analysis of the KSS function scores, foot alignments, and other variables. Lower knee extensor strength (β, 0.40; 95% CI, 0.01 to 0.33; P=0.001) and higher BMI (β, -0.35; 95% CI, -2.82 to -0.66; P=0.002) were significantly associated with lower KSS function scores, but foot alignments showed no significant association.

## Discussion

The aim of the present study was to determine whether foot alignments are associated with KSS symptom and function scores in patients with medial knee OA. To the best of our knowledge, this study is the first to comprehensively assess the association of these three foot alignments with knee symptoms and function in knee OA. The navicular/foot ratio, as a midfoot alignment index, was significantly associated with KSS symptom scores but not with the hallux valgus angle or LHA angle. However, no significant association between foot alignment and knee function was found in patients with knee OA.

Regarding the present results, we found that a smaller navicular/foot ratio was significantly associated with lower KSS symptom scores. Thus, our results suggest that decreasing navicular height is associated with milder knee symptoms. This potential mechanism may be affected by an increase of the external knee adduction moment (eKAM) during walking in patients with knee OA. The increase in eKAM leads to higher mechanical loads on the medial knee compartment, which exacerbates knee pain in patients with medial knee OA [26]. A previous study indicated that a compensatory strategy during gait leads to a relative reduction of pressure on the medial compartment of the knee [27]. When navicular height declines, foot adduction, tibia eversion, and knee internal rotation are increased by the kinematic chain [28]. Because the mechanical axis shifts to the lateral compartment of the knee owing to the kinematic chain [29], the mechanical stress in the medial knee compartment decreases with a reduction in eKAM during walking. The present study did not perform three-dimensional gait analysis; thus, the dynamic association remains unclear. However, a previous study reported that the medial compartment loads of the knee in elderly people decreased by approximately 18% when the medial foot load increased [30]. The findings of the present study suggest that lower midfoot alignment in patients with medial knee OA is associated with the alleviation of knee symptoms.

The present study showed that forefoot and rearfoot alignments were not associated with the KSS symptom scores. According to kinematic theory, foot adduction causes hallux valgus, navicular drop, and rearfoot eversion simultaneously. However, according to a previous study of elderly Japanese people, hallux valgus, navicular drop, and rearfoot eversion showed no associations [31-32]. In agreement with previous studies, no significant correlation was found between foot alignments. These facts indicate that knee OA patients have complex deformities in foot alignment, implying that their foot alignment deformity is difficult to explain kinematically. Although the mechanism of complex foot deformity is unknown, midfoot alignment, which constructs a medial longitudinal arch as a stabilization mechanism during loading, may have a greater effect on knee kinematics than forefoot or rearfoot alignment. The midfoot that forms the medial longitudinal arch is important for foot structural stabilization; therefore, midfoot alignment may have a relatively stronger mechanical association with the knee joint than forefoot and rearfoot alignments.

Regarding the relationship between KSS function scores and foot alignments, the present study did not identify any significant association. There have been several studies [11-12] on the association between knee function and foot deformity, but a consistent conclusion has not been reached. Iijima et al. reported no significant differences in JKOM activities of daily living scores or physical function between the flatfoot and control groups [11]. The results of the current study are in agreement with those of a previous study [11]. The KSS function scores assess functional disorders in activities of daily living, including gait and stair ascent/descent. Therefore, the KSS function scores were more influenced by knee extensor strength than by foot alignment. In this study, BMI and knee extensor strength were identified as significant factors affecting the KSS function scores in patients with knee OA. BMI was negatively, and knee extensor strength positively associated with KSS function scores. A previous study by Taniguchi et al. [21] showed a significant association between BMI and knee extension strength and the KSS function score, and the results of this study are in agreement. Therefore, these findings suggest that knee function is explained by knee extensor strength but not directly by foot alignment.

This study has several limitations. First, the present study considered the association between a decline in navicular height and mild knee pain from the perspective of biomechanics; however, we measured only static alignments. Second, this was a cross-sectional study; thus, foot alignments were assessed by deviation from standard alignments. To prove that a decline in navicular height compensates for alleviating knee pain in patients with knee OA, future research is required to clarify if there is a causal relationship.

In conclusion, the findings of the present study indicated that knee symptoms, but not knee function, were associated with midfoot alignment in patients with medial knee OA. Lower navicular height in patients with medial knee OA may relate with the alleviation of knee symptoms.

## Statements and Declarations

***Conflicts of Interest***

Authors declare no conflict of interest.

***Availability of data and material***

Data are not available due to ethical restrictions.

***Code availability***

Not applicable

***Authors' contributions***

All authors have made substantial contributions to (1) the conception and design of the study, (2) critical revision for important intellectual content, and (3) final approval of the version to be submitted. The specific contributions of each author are as follows:

(1) Analysis and interpretation of data: Kaede Nakazato, Masashi Taniguchi, and Noriaki Ichihashi

(2) Article drafting: Kaede Nakazato, Masashi Taniguchi, and Noriaki Ichihashi

***Ethics approval***

All study procedures were approved by the Ethics Committee of the Kyoto University Graduate School of Medicine and were conducted in accordance with the principles of the Declaration of Helsinki.

***Consent to participate and consent for publication***

Written informed consent was obtained from all participants.

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**Table 1.** The characteristics of study participants (n=79)

| Characteristics | Mean ± SD or n (%) |
|---|---|
| Age, y | 73.3±7.21 |
| Body mass index, $kg/m^2$ | 23.6±3.40 |
| Radiographic OA severities | |
| KL = 2 | 32 (41.0%) |
| KL = 3 | 24 (30.8%) |
| KL = 4 | 22 (28.2%) |
| Knee extensor strength, Nm | 87.1±31.5 |
| KSS | |
| Symptom scores, /25 | 72.2±16.8 |
| Function scores, /100 | 14.9±5.01 |
| Foot alignments | |
| Hallux valgus angle, ° | 29.8±10.8 |
| Navicular/foot ratio | 0.16±0.02 |
| LHA angle, ° | -1.91±4.65 |

Continuous variables are expressed as mean ± standard deviation (SD), and categorical variables are expressed as numbers and percentages.

Abbreviations: OA, osteoarthritis; KL, Kellgren-Lawence; KSS, Knee Society Score; navicular/foot ratio, navicular height adjusted by total foot length; LHA, leg heel alignment (inversion, +)

**Table 2.** Results of correlations coefficients between foot alignments

| | Hallux valgus angle | Navicular/foot ratio | LHA angle |
|---|---|---|---|
| Hallux valgus angle | - | 0.03 | 0.01 |
| Navicular/foot ratio | - | - | 0.09 |
| LHA angle | - | - | - |

Pearson's correlation analysis was conducted for each foot alignment

Abbreviations: navicular/foot ratio, navicular height adjusted by total foot length; LHA, leg heel alignment (inversion, +).

**Table 3.** Associations between KSS symptom scores and foot alignments and other variables using multiple linear regression analysis

| Variables | Association with KSS symptom scores | | | |
| --- | --- | --- | --- | --- |
| | B | β | P value | 95%CI |
| Hallux valgus angle, ° | -0.08 | -0.17 | 0.107 | -0.18 to 0.02 |
| Navicular/foot ratio | -64.8 | -0.30 | 0.005 | -109.2 to -20.5 |
| LHA angle, ° | -0.06 | -0.05 | 0.619 | -0.28 to 0.17 |
| Knee extensor strength, Nm | 0.05 | 0.32 | 0.004 | 0.02 to 0.09 |
| Radiographic OA severities | -0.89 | -0.15 | 0.179 | -2.18 to 0.41 |
| Age, y | 0.17 | 0.24 | 0.036 | 0.01 to 0.32 |
| Body mass index, kg/m$^2$ | -0.31 | -0.21 | 0.058 | -0.62 to 0.01 |

Multiple linear regression analyses were conducted with KSS symptom scores as the dependent variable and foot alignments as independent variables, adjusted for knee extensor strength, radiographic OA severity, age, and body mass index.

Abbreviations: B, non-adjusted regression coefficient; β, adjusted regression coefficient; CI, confidence interval; KSS, Knee Society Score; Navicular/foot ratio, navicular height adjusted by total foot length; LHA, leg heel alignment (inversion, +).

**Table 4.** Associations between KSS function scores and foot alignments and other variables, using multiple linear regression analyses

| Variables | Association with KSS function scores | | | |
| --- | --- | --- | --- | --- |
| | B | B | P value | 95%CI |

| | | | | |
|---|---|---|---|---|
| Hallux valgus angle, ° | -0.17 | -0.11 | 0.327 | -0.50 to 0.17 |
| Navicular/foot ratio | -21.3 | 0.03 | 0.780 | -173 to 131 |
| LHA angle, ° | -0.01 | <0.01 | 0.970 | -0.78 to 0.76 |
| Knee extensor strength, Nm | 0.21 | 0.40 | 0.001 | 0.10 to 0.33 |
| Radiographic OA severities | -1.29 | -0.06 | 0.566 | -5.74 to 2.73 |
| Age, y | 0.19 | 0.08 | 0.477 | -0.34 to 0.72 |
| Body mass index, kg/$m^2$ | -1.74 | -0.35 | 0.002 | -2.82 to -0.66 |

Multiple linear regression analyses were conducted with KSS function scores as the dependent variable and foot alignments as independent variables, adjusted for knee extensor strength, radiographic OA severity, age, and body mass index.

Abbreviations: B, non-adjusted regression coefficient; β, adjusted regression coefficient; CI, confidence interval; KSS, Knee Society Score; Navicular/foot ratio, navicular height adjusted by total foot length; LHA, leg heel alignment (inversion, +).

**Figure Caption**

**Fig. 1** Measurement of foot alignment

a. Measurement of hallux valgus angle:

Measure the angle of intersection of the axes of the first metatarsal and first proximal phalanx.

b. Measurement of navicular height:

Mark the top of the navicular tuberosity.

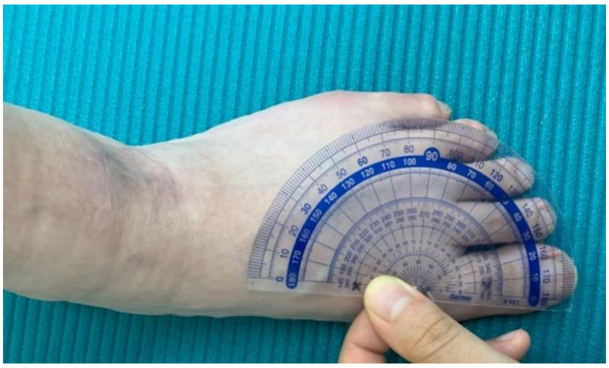
Measure the distance from the floor to the navicular tuberosity.

c. Measurement of LHA angle:

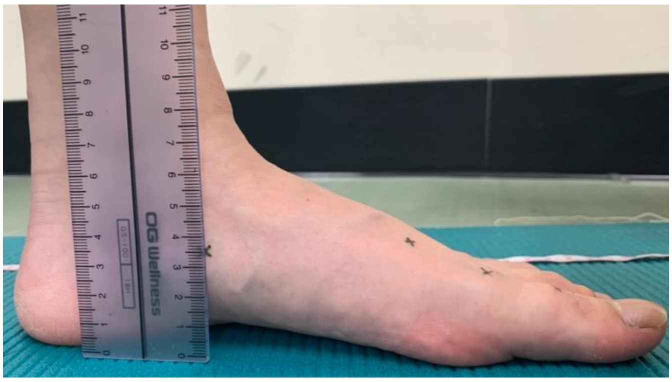
Measure the angle between the midline of distal leg and that of the calcaneal axis.

**Fig. 1 Measurement of foot alignment**

**a**



**b**




c