The association between the flat feet and the symptoms of knee osteoarthritis

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Abstract

Objective: The purpose of this study was to assess the association between the flat feet and the symptoms of knee osteoarthritis (OA).

Methods: 95 participants with knee osteoarthritis were recruited for this study. Knee osteoarthritis was evaluated using a combination of Kellgren-Lawrence (K-L) grade, femoral-tibial angle (FTA), knee pain and physical function. The Arch Index (AI) was used to assess the severity of flat feet, with subjects being divided into groups with no flat feet, mild flat feet and severe flat feet. A chi-square test, continuous variable t test and Mann-Whitney U test were used to compare differences in K-L grade, knee pain, physical function and femoral-tibial angle. Regression analysis was performed to assess the correlation between the flat feet and the characteristics of knee osteoarthritis.

Results: Flat feet was associated with a significantly increased risk of having a larger varus angle (beta: -2.306; 95% confidence interval (CI): -3.703, -0.909; $p = 0.001$), higher pain score (beta: 0.356; 95% CI: 0.130, 0.582; $p = 0.002$) and greater loss of physical function (beta: 0.281; 95% CI: 0.071, 0.491; $p = 0.009$). Severe grades of flat feet were associated with an increased risk of pain (beta: -0.289; 95% CI: -0.543, -0.035; $p = 0.026$). However, the severity of flat feet was not associated with K-L grade, FTA or physical function.

Conclusion: There was a significant association between the presence of flat feet and symptoms of knee OA, and severe flat feet was found to aggravate OA-related knee pain. Active treatment to correct flat feet is recommended to relieve symptoms associated with knee OA.

Level of Evidence: Level II

1 Background

Knee osteoarthritis (OA) is a debilitating joint disease most prevalent in middle-aged and older adults[1]. It typically leads to pain and dysfunction in the knee joint, which often has a considerable debilitating effect on a person's quality of life[2].

Evidence suggests that many of the characteristic features of knee OA are related to mechanical loading[3]. The foot plays an immediate role in absorbing mechanical stresses from ground contact and sculpting the pattern of postural alignment and joint motion at the knee and throughout the lower extremity[4]. During weight-bearing activities, the posture and motion of the foot and knee are coupled within a closed kinematic chain. This kinematic coupling may cause excessive rotation of the knee in people with flat feet[5]. A growing body of evidence supports the basic premise that the mechanics of the foot and knee are interdependent[5]. Their interdependence may contribute causally to some knee pathologies, including knee OA.

It has been reported that flat feet frequently lead to knee pain and damage to the medial cartilage[6]. Moreover, people with flat feet are more likely to have knee OA[7]. Studies have also shown that for patients with symptoms of knee OA combined with flat feet, the level of knee pain can be significantly improved by correcting the symptoms of flat feet[8]. Despite evidence suggesting a biomechanic link between flat feet morphology and mechanical stress on the knee, previous studies on the association between flat feet and OA-induced knee pain only considered the presence of flat feet as a factor[9], but the severity of the flat feet was not evaluated. Moreover, besides knee pain, knee OA can manifest in other ways, including knee degeneration, knee malalignment, reduced joint motion, and knee dysfunction. Thus, the association between these symptoms of knee OA and the presence and severity flat feet still needs to be evaluated.

There are three methods used extensively to assess characteristics of knee OA: Kellgren and Lawrence (K-L) grading system, femoral-tibial angle (FTA), and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC). (i) The K-L grading system characterizes osteoarthritis on a scale of 0 - 4 based on the presence and condition of osteophytes, articular cartilage, subchondral bone sclerosis and other symptoms. This method has shown good reliability in assessing knee osteoarthritis and is commonly used when making a medical assessment of the severity of knee OA[10]. (ii) The femoral-tibial angle (FTA) refers to the angle between the axis of the femur and the axis of the tibia. It is an important biomechanical evaluation index for the knee, and is closely related to the occurrence of knee OA[5]. Often with pathological conditions the centers of the hip, knee, and ankle joints are offset, and may relate to the worse symptoms of knee OA. In such situations, the axis of the femur and the axis of the tibia intersect to form an angle, called the femoral-tibial angle (FTA). The FTA is an important biomechanical evaluation index for the knee, which is often used to describe the lower limb force line, and is closely related to the occurrence of knee OA. More negative values indicated a larger varus angle (refer to Supplementary data), which means the worse symptoms of knee OA. (iii) Knee OA often impairs leg function, limits daily activities and causes less active knee[11]. The WOMAC scale is a commonly used self-administered scoring standard for evaluating knee OA and the effectiveness of treatment based on symptoms and the performance of daily activities. This scoring standard evaluates the degree of knee OA in three areas, which are knee pain, stiffness, and physical function[12].

The purpose of this study was to systematically assess the cross-sectional relationship between the severity of flat feet and the symptoms of knee OA with regard to knee degeneration, knee malalignment, knee pain and knee function by using the K-L grading system, FTA, and WOMAC scale. It was hypothesized that the presence of flat feet would be significantly associated with OA-induced knee pain, lower limb FTA and lower physical function. Understanding the association between flat feet and knee OA would allow effective treatment methods to be devised, and altering foot posture using appropriate shoes, arch supports, or foot orthoses may reduce the risk of symptomatic knee OA.

2 Materials And Methods

Study population

This study is a cross-sectional, observational cohort investigation into knee OA. All protocols were approved by the Beihang University Biological Science and Medical Engineering Review Board (No. : BM20200096) and written consent was obtained from all participants prior to participation after being given detailed instructions on the protocols.

The participants in this study were recruited from an outpatient community orthopedic clinic. As the purpose of this study is to evaluate whether flat feet may aggravate knee OA symptoms, invitation letters for participation were sent to all patients of the clinic who had been diagnosed as having knee osteoarthritis in the month of August 2019 according to the American College of Rheumatology Clinical Criteria[13] (n = 146). The inclusion criteria were knee pain, no history of knee surgery, no rheumatoid osteoarthritis, no inflammatory arthritis, no previous joint injury and being able to walk independently. Of the patients providing positive responses (n = 120), adequate foot posture data could not be located for 23 patients and knee radiographs could not be located for 2 patients. The remaining patients (n = 95) comprised the study population, of whom 84 participants exhibited bilateral knee OA and 11 participants exhibited unilateral knee OA. Characteristics of all participants are shown in Table 1.

Table 1
Demographic characteristics, knee-level characteristics, and foot posture of the research population. (n=95).

Subject characteristics	
Age (years)	58.0±10.5
Male, N (%) / Female, N (%)	14 (14.7) / 81 (85.3)
BMI (kg/m²), Median (IQR)	25.76±3.35
Knee-level characteristics	
Severity of knee OA (K-L grade), N (%)	
K-L 2	28 (29.5)
K-L 3	51 (53.7)
K-L 4	16 (16.8)
FTA (°)	-7.23±3.33
Pain (WOMAC score), Median (IQR)	1.97±0.54
Physical function (WOMAC score), Median (IQR)	1.73 ±0.49
Foot posture (AI value)	0.68 ±0.37
Foot posture assessment	

Foot posture was assessed using the arch index (AI). To calculate the AI, static footprints were obtained from each subject when standing in a relaxed bipedal stance on a foot printer (Mingscan Footprinter MP-5, Vers Tech Science Co. Ltd., Taiwan) with toes pointed forward. The AI value was calculated as the ratio of the length from point c to point d (Line cd) and from point c to point e (Line ce)[14] (Fig. 1). The lengths of Line cd and Line ce were measured three times (accuracy: 0.1mm). The mean AI from the three calculations was used as the value for that foot. A participant was deemed as having flat feet when AI $\leq$ 0.84. Flat feet within the range of $0.84 \geq AI > 0.42$ were defined as mild flat feet, and those with a value $0.42 \geq AI$ were deemed severe flat feet[14]. The intra-interclass correlation coefficient (ICC) was 0.993 for AI, suggesting good reliability across the measurements[15].

Assessment of OA-related knee symptoms

Weight bearing anteroposterior radiographs were obtained from each participant with the patella facing forward and the legs in full extension. All radiographs were taken in the same medical imaging department using the same machine (uDR 770i, United Imaging Healthcare Co., Ltd., China). The severity of knee OA was quantified using the Kellgren and Lawrence (K-L) grading system with a range of 0 - 4. Femorotibial alignment was quantified by the femoral-tibial angle (FTA) (α). The FTA measurement method recommended by Moyer et al.[16] was used in this study, as this method uses short knee films and has been proven to give comparable results to long hip-knee-ankle films for the prediction of femorotibial alignment. Using this method, the anatomical FTA range for males is $-5°<\alpha< -1°$ and for females is $-7°<\alpha< -3°$[16]. More negative values indicated a larger varus angle (refer to Supplementary data). The FTA of each knee was measured on radiographs using the software PicPick (version 5.0.7, Korea) (accuracy: 0.01°). The angle was measured three times by a single investigator with an interval of one week between measurements. The average of the three measurements was used as the FTA for that knee. Knee pain and physical function were evaluated using the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) interview technique[12]. Each of the 24 items assessed with this method was graded on a five-point Likert scale ranging from 0 to 4. The score for each parameter (pain, stiffness, and physical function) was calculated as the sum of all the constituent item scores divided by the number of items assessed. A high score reflected a high severity for that parameter. This study did not consider the stiffness scores because of the limited evaluation of knee stiffness in the WOMAC survey[17]. The intra-interclass correlation coefficient (ICC) was 0.913 for FTA, 0.920 for K-L grade, 0.991 for pain, and 0.993 for function, suggesting good reliability across all measurements[15].

Statistical analysis

To minimize any bias produced by similarities between the right and left knees of the same subject[18], only the affected side was selected for evaluation. To eliminate the confounding variable of bilateral involvement, the more painful side was selected in each patient[19].

This study assessed whether the presence or severity of flat feet was associated with the symptoms of knee OA. Categorical variables were summarized as a number (%) and continuous variables were summarized as a mean (standard deviation (± SD)) or median (interquartile range (IQR)), as appropriate.

The patients were divided into groups without flat feet, with mild flat feet and with severe flat feet, and differences in knee symptoms between the groups were compared.

The study used 4 variables to describe the condition of each knee, with an appropriate statistical analysis method chosen depending on the continuity and normality of the variables. K-L is a categorical variable, divided into four levels (I, II, III, IV). Therefore, the Chi-square test for dichotomous variables was used to compare the difference in K-L between groups. FTA, pain score, and physical function are continuous variables. The normality test for continuous variables showed that FTA and functional scores conformed to a normal distribution, but the pain scores did not. Therefore, a t test for continuous variable was used to compare differences in FTA and physical function between the different groups, and the Mann-Whitney U test for non-parametric continuous variable was used to compare differences in pain scores. The software PASS version 15 (NCSS, LLC, Kaysville, UT, USA) was used to calculate sample sizes. A priori power analysis with a significance level of 0.05 (type - I error), a desired power of 90%[20] and the effect size or odd ratio was used to evaluate the sample size. The required sample size was calculated for the three tests above, among which the maximum sample size required was 68 individuals.

Linear regression was used to assess the association between flat feet and symptoms of knee OA[18]. Binary linear regression was used to analyze the effects of the presence of flat feet (with or without flat feet) or severity of flat feet (mild and severe) on the FTA, pain score and physical function, because these parameters are continuous. Ordinal logistic regression was used to analyze the impact on the K-L grade, because K-L is considered an ordered discrete variable. In the regression analyses, the parameters for assessing knee OA symptoms (severity of knee OA, FTA, pain and physical function) were assigned as dependent variables and the presence of flat feet (with or without) or severity of flat feet (mild and severe) were assigned as independent variables. Age, sex, and BMI are known to be associated with both flat feet and knee OA[18], and so were used as covariates to adjust the regression models.

SPSS 22.0 (SPSS, IBM, USA) was used for all the statistical analyses. Significance was set as $p<0.05$.

3 Results

Figure 2 shows a flow chart of all participants enrolled in this study. Of the 95 participants recruited and diagnosed with knee OA, 65 participants had flat feet, accounting for 68.4% of the research group. For the OA subjects with ipsilateral flat feet, 37 of the knees were accompanied by mild flat feet and 28 had severe flat feet. All knees in this study had a K-L grade of 2 to 4, because each was previously diagnosed as having OA by a professional surgeon, according to the American College of Rheumatology Clinical Criteria[13].

The results of the univariate analyses in Table 2 indicate that the subjects with ipsilateral flat feet had a significantly larger varus angle(FTA) (-7.96 (SD: 3.03)) than those with healthy feet (-5.65 (SD: 3.50)) (p = 0.001). For the subjects with both knee OA and flat feet, the knee pain (2.08(SD: 0.52) vs. 1.72(SD: 0.50), p = 0.002), physical function (1.82 (SD: 0.51) vs. 1.53(SD: 0.40), p = 0.009) and K-L grades (2.63 vs. 2.99, p = 0.039) were also more severe than those without flat feet.

Table 2
Knee-level characteristics of the research knees based on the presence of flat feet (n=95).

Variables	Without flat feet (n = 30 knees)	With flat feet (n = 65 knees)	p - Value†
Severity of knee OA (K-L grade), N (%)			**0.039**
K-L 2	**14 (46.7)**	**14 (21.5)**	
K-L 3	**13 (43.3)**	**38 (58.5)**	
K-L 4	**3 (10.0)**	**13 (20.0)**	
FTA (°)	**-5.65±3.50**	**-7.96±3.03**	**0.001**
Pain (WOMAC score), Median (IQR)	**1.72±0.50**	**2.08±0.52**	**0.002**
Physical function (WOMAC score), Median (IQR)	**1.53±0.40**	**1.82±0.51**	**0.009**

The results of the univariate analyses in Table 3 showed that comparing the knee symptoms of patients with mild flat feet and severe flat feet, there was a significant differences in pain scores (1.96(IQR: 1.12,3.20) vs. 2.12(IQR: 1.28,3.50), p = 0.045) and KL grades (2.89 vs. 3.11, p = 0.028) between the two groups. There was no significant difference in FTA (-7.37(SD: 3.16) vs. -8.73(SD: 2.72), p = 0.073) and physical function (1.64(IQR: 1.08,2.69) vs. 1.91(IQR:1.11,3.48), p = 0.533) between the subjects with mild flat feet and severe flat feet.

Table 3
Knee-level characteristics of the research knees based on the severity of flat feet (n=95).

Variables	Mild flat feet (n=37 patients)	Severe flat feet (n=28 patients)	p - Value†
Severity of knee OA (K-L grade), N (%)			**0.028**
K-L 2	**12 (32.5)**	**2 (7.1)**	
K-L 3	**17 (45.9)**	**21 (75.0)**	
K-L 4	**8 (21.6)**	**5(17.9)**	
FTA (°)	-7.37±3.16	-8.73±2.72	0.073
Pain (WOMAC score), Median (IQR)	**1.96(1.12,3.20)**	**2.12(1.28,3.50)**	**0.045**
Physical function (WOMAC score), Median (IQR)	1.64(1.08,2.69)	1.91(1.11,3.48)	0.533

† p – Values from Chi-squared test for categorical variables presented as N (%), t-test for normal continuous variables presented as mean±SD, and Mann-Whitney U Test for variables presented as median (IQR). Bold values represent statistically significant results.

Table 4 details the results of the regression analyses showing the risk of aggravating knee OA symptoms according to whether subjects had flat feet and the severity of flat feet. The results indicate that having flat feet was associated with a significantly increased risk of having a higher K-L grade (proportional odds ratio (OR): -1.126; 95% CI: -2.010, -0.241; p = 0.075), larger varus angle(FTA) (beta: -2.306; 95% CI: -3.703, -0.909; p = 0.001), higher pain score (beta: 0.356; 95% CI: 0.130, 0.582; p = 0.002) and greater loss of physical function (beta: 0.281; 95% CI: 0.071,0.491; p = 0.009).

Table 4
Regression analyses on the risk of developing knee symptoms according to the presence of flat feet and the severity of flat feet.

Flat feet	Risk for knee symptoms							
	Severity of knee OA (K-L grade) ††		FTA		Pain		Physical function	
	OR (95% CI)	p-Value	Beta(95% CI)	p-Value	Beta (95% CI)	p-Value	Beta (95% CI)	p-Value
presence of flat feet	-1.126 (-2.010, -0.241)	0.075	**-2.306 (-3.703, -0.909)**	**0.001**	**0.356 (0.130, 0.582)**	**0.002**	**0.281 (0.071,0.491)**	**0.009**
Severity of flat feet	0.644 (-0.383, 1.670)	0.219	1.359 (-0.132, 2.851)	0.073	**-0.289 (-0.543, -0.035)**	**0.026**	-0.134 (-0.398, 0.121)	0.298

† Multiple regression models were fitted, unless otherwise noted. †† Ordinal Regression model was fitted. OR: odds ratio; CI: confidence interval. Bold values represent statistically significant results.

The results also show that flatter feet, increasing from mild to severe, were associated with a significantly increased risk of reporting a higher pain score (beta: -0.289; 95% CI: -0.543, -0.035; $p = 0.026$). The severity of flat feet was not associated with the K-L grade ($p = 0.219$), FTA ($p = 0.073$) or physical function ($p = 0.298$).

4 Discussion

This study assessed the association between flat feet and symptoms of the knee joint commonly associated with osteoarthritis (OA). The most important findings are that (i) the presence of flat feet was significantly correlated with an increased likelihood of having severe knee OA symptoms, and (ii) more severe grades of flat feet were associated with a significantly increased risk of having OA-induced knee pain. These findings may have implications for the treatment of knee OA in the adult population.

This study considered all patients who were diagnosed as having knee OA within a one-month period (August 2019) at an orthopedic clinic. The average age of the patients in this study was 58 years old, and 83.2% of the patients had a K-L grade of 2-3. A study by Kao and Tsai[21] followed up on patients with knee OA in Taiwan who primarily had a K-L grade of 2/3 and an average age of 56.86 years old, which was similar to the patient cohort in this study, this fully reflects that the results of this study are worthy of being promoted. This study used readings of the arch index to determine the grade of flat feet, and found that 68.4% of participants had flat feet. This value is much higher than the percentage of flat feet in the general population (22% - 26.2%)[22, 23], which indicates that people with knee OA are more likely to have flat feet. This result is also higher than other studies on the reported distribution of flat feet in patients with knee OA (42% - 49.5%)[18, 22]. A likely reason for the difference is that for patients in this study who suffered bilateral knee OA and had an equal level of pain in each knee, the side with more severe flat foot was selected as the research object. This complimented the research goal to assess the relationship between flat feet and knee OA, but likely also resulted in a higher incidence of flat feet than previous studies.

This study found a significant correlation between the presence of flat feet and K-L grade. The K-L grade is an index commonly used in orthopedics to assess the severity of knee OA. The greater the K-L grade, the more severe the cartilage damage and knee deformity. The results showed a significant difference in K-L grade between the groups with and without flat feet, indicating that the presence of flat feet may aggravate OA symptoms. Similarly, Gross et al.[6] reported that people with flat feet were 1.4 times more likely to suffer from medial cartilage damage, indicating that the presence of flat feet may increase the risk of cartilage damage in the knee. However, there was no significant correlation between the severity of flat feet and K-L grade, meaning that having severely flat feet did not put the subjects at greater risk of developing severe cartilage damage or knee deformities. The primary influencer was whether a subject had flat feet, while the severity of flat feet did not play a significant role in determining knee symptoms.

Femorotibial alignment was shown to be significantly associated with the presence of flat feet. The lower extremity may be considered as a biomechanical system with a mechanical link between the hip, knee, ankle and foot[5]. Abnormal foot motion, loading patterns and alignment of the foot may induce varus knee as a compensatory mechanism[24]. Okamoto et al.[25] found that severe knee deformities were more likely to be compensated by an involuntary adjustment of hindfoot alignment. As a conservative treatment, foot orthoses are commonly used to correct foot posture, with the intent of realigning the lower limb through changes in lower extremity kinematics. This balances the loading on the knee joint by changing the femoral-tibial angle (FTA)[26]. Orthotics such as lateral wedge insoles may be used to shift the center of pressure of the foot, subsequently reducing the knee adduction moment and improving the varus femorotibial alignment[27]. Consequently, high pressure zones are dispersed after the varus alignment is improved, and the pressure on the cartilage per unit area is reduced. A meta-analysis on the effectiveness of lateral wedge insoles in the treatment of medial knee OA found that such insoles can improve the symptoms of knee osteoarthritis by increasing the FTA[28], and can effectively slow the progression of degenerative knee OA. In this study, although patients with flat feet showed more negative FTA, there was no significant difference in FTA between patients with different severity of flat feet. This may be explained by a study by Araújo et al.[29] in which it was found that when the arch of the foot collapses to a certain extent, the kinematics of the foot-ankle complex play a major role in preventing further degeneration of the arch, as well as relieves symptoms on the knee and inhibits further deterioration of the FTA.

Knee pain is the most intuitive factor for patients to sense the degree of disease, and relieving pain is the basic standard for improving quality of life. In a cross-sectional study involving 1903 subjects, Gross et al.[6] found that subjects with flat feet were 1.3 times more likely to have knee pain than with other foot shapes. Using the Japanese knee OA measurement method to quantitatively evaluate OA-related knee pain and disability, Iijima et al.[18] also found that the presence of bilateral flat feet was significantly associated with OA-related knee pain. In our study, the pain of knee OA was significantly associated with the presence ($p=0.002$) and severity ($p=0.026$) of flat feet, which means that improving flat feet may relieve knee OA-induced pain. The arch of the foot is important for weight-bearing and shock absorption, and plays a critical role in the kinematics of the knee, which can be explained by the rotational coupling between the joints[9]. A low arch in flat-footed patients may affect the pressure distribution in the knee and cause knee pain.

Similar to Guler et al.[4], this study used the WOMAC system to evaluate physical function, with the results showing a connection between the presence of flat feet and physical function. Symptomatic knee OA is well known to cause knee pain and disability[30], and the additional presence of flat feet may further aggravate the disability. Poor arch formation accompanied by knee pain may be the reason why flat footed patients reported lower physical function than those without flat feet. However, there was no significant correlation between physical function and the severity of flat feet. Compensatory mechanisms, such as forces from surrounding muscles and ligaments, may act to alleviate some of the knee dysfunction[31].

The relationship between flat feet and OA-related knee symptoms in this study supports the proposal that knee OA can be treated using simple low-cost interventions to correct foot posture. The results showing that a small change in one factor may alter another demonstrate how correcting flat feet (for example, through surgery or orthoses) can be used to relieve symptoms of knee OA. These results may be used to develop a suitable conservative treatment plan for patients suffering from knee OA combined by flat feet.

There are some limitations to this study that should be noted. First, there was some selection bias in this study when choosing the patient population, in which only older participants were included with a mean age of 58.0 years. The results may not accurately reflect the conditions in a younger population. The participants came from a pool of patients who were previously diagnosed as having knee OA, and thus the sample pool was composed of a high percentage of older and female subjects[32, 33]. Second, this study did not consider other influential factors such as ipsilateral foot pain and physical performance when assessing the correlation between flat feet and knee OA. We cannot preclude the possibility that pain in other joints may contribute to the relationship between flat feet and knee pain and physical function. Future studies on other possible influential factors are warranted to confirm the negative effect of the severity of flat feet on knee pain and function. Third,, the patient sample size in this study was low, which limited the ability to generalize the results to other populations, and the study divided the severity of flat feet into just two categories (mild and severe) because the number of subjects with moderate symptoms was too small to support the use of statistical analysis. Finally, the cross-sectional design of the study restricts our ability to infer the direction of causation in the observed associations. It is conceivable that structural damage in the knee is a primary cause of both flat foot and knee pain. Knee OA is a multi-factorial disease, so it is difficult to determine a specific cause. This study found a significant correlation between flat feet and knee OA, prompting us to pay attention to the impact of flat feet on knee OA.

5 Conclusions

This study evaluated the association between the presence and severity of flat feet and the symptoms of knee OA by assessing the K-L grade, femorotibial alignment, and loss of physical function. The results showed a significant association between the presence of flat feet and symptoms of knee OA, and also that severely flat feet aggravated OA-related knee pain. For osteoarthritic patients with flat feet, it is recommended that active treatment be sought to correct the flat feet and promote a higher arch. The results of this study indicate that such a correction can be expected to relieve symptoms of knee OA. These findings could set a foundation for developing a conservative treatment plan for knee OA by altering foot morphology.

Abbreviations

OA: osteoarthritis; K-L: Kellgren-Lawrence; FTA: femoral-tibial angle; AI: Arch Index; CT: Computed Tomography; CI: confidence interval; SD: standard deviation; IQR: interquartile range.

Declarations

Ethics approval and consent to participate

This study followed the principles of the Declaration of Helsinki, and its protocol was approved by the Beihang University Biological Science and Medical Engineering Review Board (No.: BM20200096). All the subjects involved in the study were conscious adults who were fully responsible for their actions. All the subjects have been informed of the details of the study and how to use their data. After understanding detailed instructions on the protocol, written informed consent was obtained from all participants prior to participation.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated during and analyzed during the current study are not publicly available due to protect the privacy of patients, the data was not actively disclosed, but are available from the corresponding author on reasonable request.

Competing Interests

The authors declare that they have no competing interests.

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Authors' Contributions

CKC: Conceptualization; Methodology; Project administration; Supervision; Writing-review & editing. MW: Conceptualization; Resources; supervision; Writing-review & editing. MZ: Formal analysis; Data curation; Writing-Original draft preparation; Writing-review & editing. MDN: Formal analysis; Investigation; Data curation; Writing-Original draft preparation; Writing- review & editing. XZQ: Writing-Original draft preparation; Writing-review & editing. SK: Data curation. YYS, JWL and ZYZ: Investigation. All authors have agreed to be personally accountable for their own contributions and ensure that questions related to the accuracy and integrity of any part of the work have been appropriately investigated and resolved with reference to the literature when needed. All authors have read and agreed to the published version of the manuscript.

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Figures

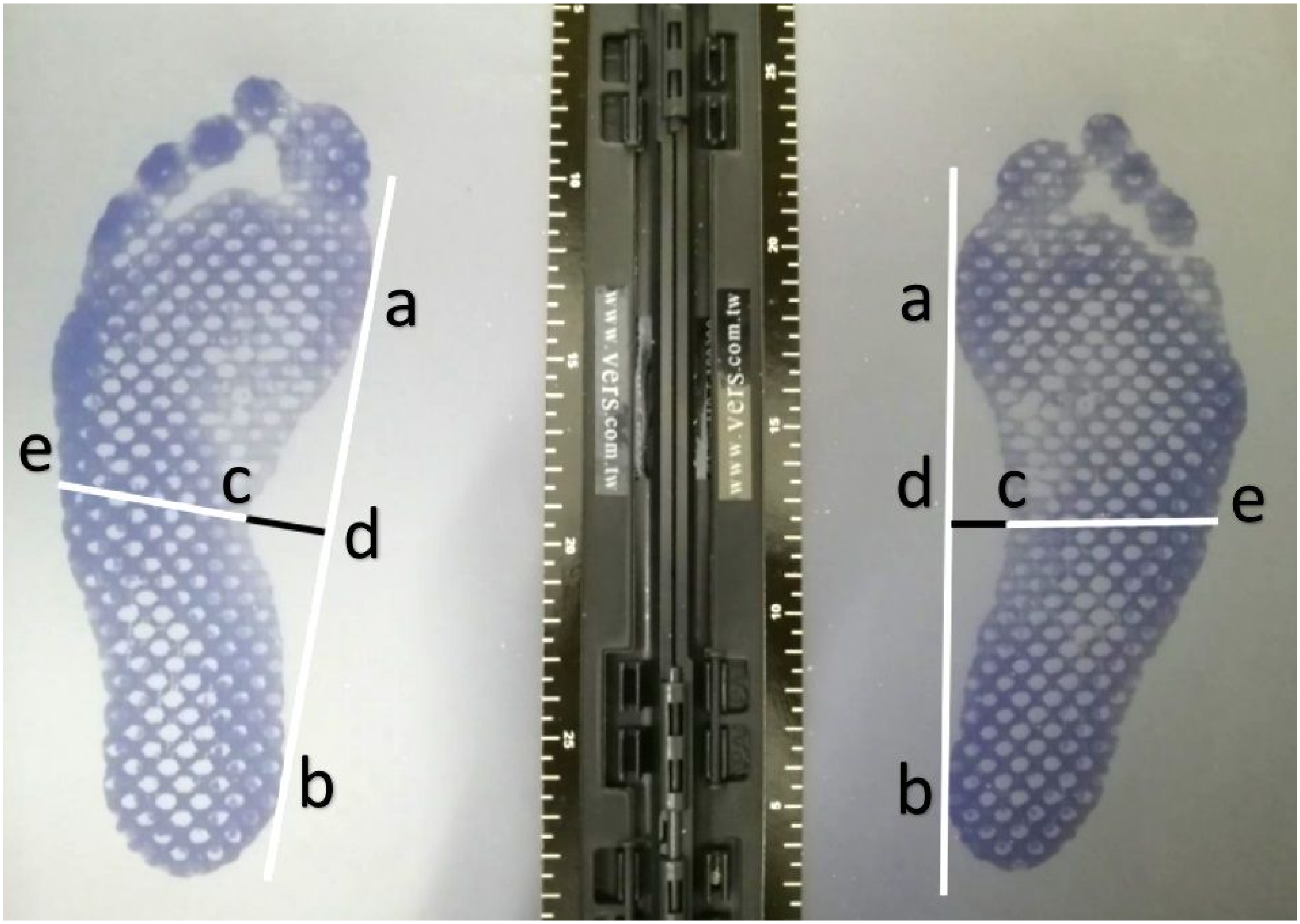

Figure 1

Ratio measurement method using footprints. a: the most medial point of the sole; b: the most medial point of the heel; c: the most concave point on the foot profile; d: perpendicular line from point c to line ab; e: intersection between line

cd and the lateral profile of the foot.

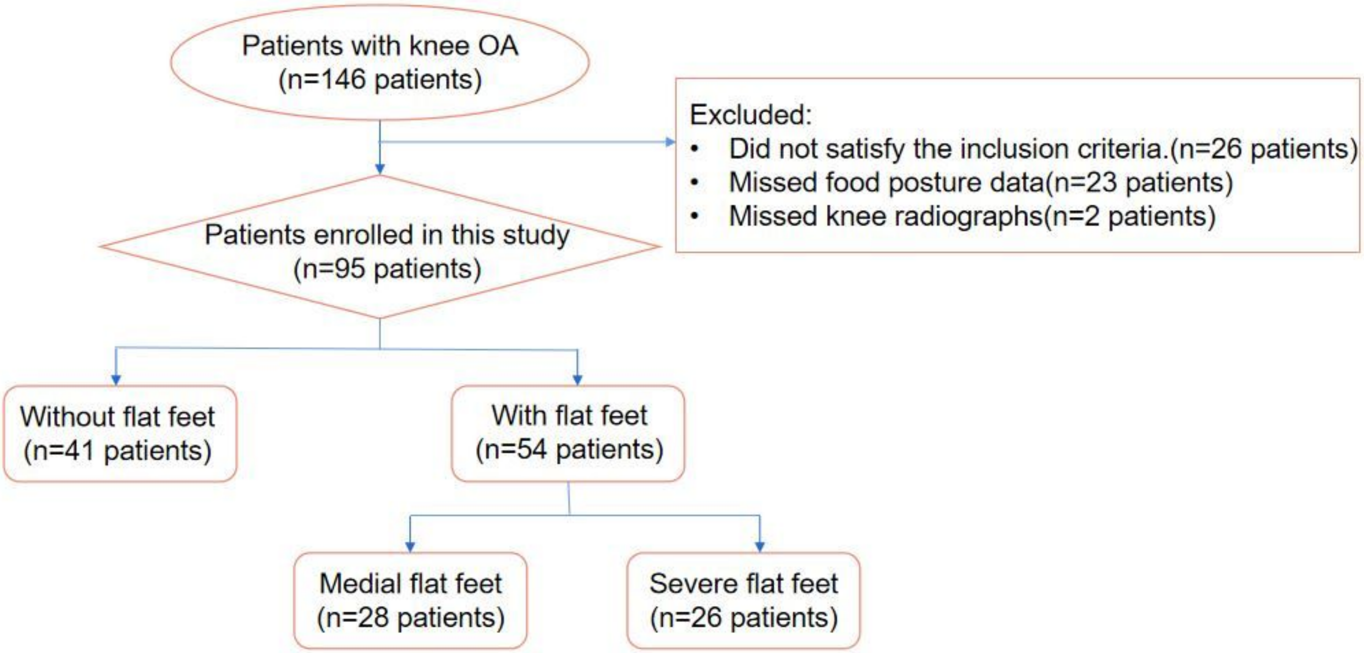

Figure 2

Flow chart showing the distribution of study participants.

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