



Research Article

Correlation Of Knee Alignment with Ankle and Hindfoot Alignment and Clinical Severity in Grade IV Osteoarthritis Knee: A Cross-Sectional Study

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Received: 28-09-2025

Accepted: 13-10-2025

Available online: 26-10-2025

ABSTRACT

Background: Osteoarthritis (OA) of the knee is a chronic degenerative disorder characterized by progressive joint deterioration. Coronal plane malalignment of the knee joint is frequently associated with advanced osteoarthritis. However, limited evidence exists regarding the relationship between knee alignment and concurrent ankle and hindfoot alignment changes in patients with severe knee OA.

Objective: To evaluate the correlation of knee alignment with ankle and hindfoot alignment and clinical severity in patients with Grade IV knee osteoarthritis.

Methods: This observational cross-sectional study was conducted at the Department of Physical Medicine and Rehabilitation, Safdarjung Hospital, New Delhi. Seventy-seven patients diagnosed with primary knee osteoarthritis (Kellgren-Lawrence Grade IV) according to American College of Rheumatology criteria were enrolled after obtaining informed consent. Knee alignment was assessed using hip-knee-ankle (HKA) angle on full-length weight-bearing anteroposterior radiographs. Ankle and hindfoot alignment were evaluated using five radiological parameters: angle between mid-diaphyseal line of tibia and calcaneus (ADTC), tibiotalar angle (TTA), tibial anterior surface angle (TAS), talar tilt angle (TT), and angle between ground surface and distal tibial plafond (GP). Clinical severity was assessed using Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Health Assessment Questionnaire (HAQ), and Visual Analogue Scale (VAS). Spearman rank correlation coefficient was used for statistical analysis.

Results: The mean age of participants was 59.98 ± 8.44 years, with 62.3% females. Mean disease duration was 6.67 ± 2.86 years. The mean HKA angle was 13.24 ± 3.92 degrees, indicating substantial varus malalignment. HKA showed statistically significant positive correlations with ADTC ($r=0.262$, $p=0.001$), TTA ($r=0.330$, $p<0.001$), TAS ($r=0.343$, $p<0.001$), and GP ($r=0.421$, $p<0.001$), with GP demonstrating the strongest correlation. No significant correlation was found with TT ($r=-0.042$, $p=0.606$). Mean clinical severity scores indicated severe disease burden: WOMAC 64.52 ± 5.45 , HAQ 16.95 ± 3.18 , and VAS 6.12 ± 0.54 . HKA angle showed highly significant positive correlations with all clinical severity parameters: VAS ($r=0.279$, $p<0.001$), WOMAC ($r=0.579$, $p<0.001$), and HAQ ($r=0.524$, $p<0.001$), with WOMAC demonstrating the strongest association.

Conclusion: Knee varus deformity in Grade IV osteoarthritis is significantly correlated with ankle and hindfoot malalignment, as well as clinical severity. The ground-plafond angle showed the strongest correlation with knee alignment among ankle-hindfoot parameters, while WOMAC score showed the strongest association with clinical outcomes. These findings suggest that knee osteoarthritis affects the entire lower extremity as an integrated biomechanical system. Comprehensive assessment including ankle and hindfoot evaluation may improve management planning and prognostic assessment in patients with severe knee osteoarthritis.

Keywords: Knee osteoarthritis, knee alignment, ankle alignment, hindfoot alignment, HKA angle, WOMAC, lower limb biomechanics, varus deformity.

INTRODUCTION

Osteoarthritis (OA) is a chronic degenerative disorder of multifactorial etiology characterized by loss of articular cartilage, hypertrophy of bone at the margins, subchondral sclerosis, and a range of biochemical and morphological alterations of the synovial membrane and joint capsule (1). The prevalence of osteoarthritis in India is estimated at 13.2%, representing a significant burden on healthcare systems (2). Among the various joints affected by OA, the knee is one of the most commonly involved, along with the hip, first metatarsophalangeal joint, distal interphalangeal joints, and cervical and lumbosacral spine (2). Wrist, elbow, and ankle joints are typically spared in primary osteoarthritis (2).

Patients with knee osteoarthritis typically present with knee pain, joint stiffness, decreased muscle strength, and proprioception deficits. Subsequently, they often develop poor neuromuscular control, reduced walking speeds, decreased functional ability, and an increased susceptibility to falls (3). The World Health Organization has identified knee osteoarthritis as likely to become the fourth most important global cause of disability in women and the eighth most important in men (4). Worldwide estimates indicate that 9.6% of men and 18% of women aged 60 years and above have symptomatic osteoarthritis with impaired mobility (5).

The typical progression of osteoarthritis involves several key pathological events: loss of cartilage matrix making the joint more susceptible to injury; alterations to underlying bone with development of osteophytes at the periphery of the affected joint; release of cartilage or bone fragment debris into the joint; and cartilage breakdown associated with synovial inflammation leading to release of cytokines and enzymes that exacerbate cartilage damage (6,7). These factors appear to be related to the variable rate of progression in knee osteoarthritis.

In daily activities, the knee often encounters repetitive impulsive loading, a condition that requires great stability to protect the joint (8). The breakdown of protective and stabilizing mechanisms may initiate or contribute to arthritic changes in a joint (6). One factor shown to play a significant role in knee osteoarthritis is knee alignment. Historical recall of knee malalignment in childhood, such as bow legs or knock knees, is associated with a five-fold increased risk of osteoarthritis progression in adulthood (9).

The Kellgren and Lawrence classification system, proposed in 1957 and accepted by the World Health Organization in 1961, has been commonly used as a radiographic grading tool in epidemiological studies of osteoarthritis, including studies from the Framingham Osteoarthritis cohort (10,11). This classification system grades osteoarthritis from Grade 0 (no radiographic findings) to Grade 4 (large osteophytes with marked joint space narrowing, severe sclerosis, and definite bone contour deformity) (10).

Knee malalignment, particularly in the coronal plane, is often associated with advanced osteoarthritis and is considered both a risk factor for progression and a predictor of functional decline in patients with osteoarthritis (9,12). Sharma et al. demonstrated in their landmark 2001 study that knee alignment plays a crucial role in disease progression and functional decline, with increases in pain and functional deterioration accompanying increasing malalignment (9). They also found that Kellgren-Lawrence grade progression increases with increasing varus malalignment (9).

Medial compartment involvement is predominant in knee osteoarthritis, with the medial compartment affected nearly ten times more often than the lateral compartment (13). This predilection is explained by the fact that the medial compartment of a normal knee joint bears approximately 70% of body weight, whereas the lateral and patellofemoral compartments bear the remaining 30% (13). The changes in the mechanical axis lead to stress concentration in the medial compartment and degeneration of the cartilage and meniscus, which are the major pathological manifestations of knee OA (14).

Hip, knee, and ankle joint alignment collectively affect the overall alignment of the lower extremity. Consequently, any disturbance in one of these joint alignments results in alteration of lower limb alignment (15,16). Long-term pathological processes in severe knee osteoarthritis could change the alignment of the entire lower limb and accelerate degeneration of the ankle joint (17). Changes in ankle mechanical stability have been documented in patients with knee osteoarthritis, suggesting that the effects of knee pathology extend beyond the joint itself (17).

From a biomechanical perspective, ankle alignment plays an important role in knee osteoarthritis owing to rotational coupling between the hindfoot and tibia. The ankle responds to varus knee deformities as an important part of lower extremity alignment. Several previous studies have reported that radiological malalignment occurs in both ankle and hindfoot joints secondary to varus knee deformities (18-20). Lee and Jeong documented radiologic changes in the ankle joint following total knee arthroplasty, suggesting that correction of knee alignment influences distal joint mechanics (18). Gao et al. demonstrated the influence of knee malalignment on ankle alignment in both varus and valgus gonarthrosis based on radiographic measurements (19).

Secondary malalignment in the ankle and hindfoot as a result of knee deformities has been consistently reported in the literature (18-20). An association between frontal plane knee alignment and foot posture was demonstrated by Ohi et al.

in patients with medial knee osteoarthritis (21). Okamoto et al. emphasized the clinical usefulness of hindfoot assessment for total knee arthroplasty, noting persistent postoperative hindfoot pain and alignment issues in patients with pre-existing severe knee deformity (22).

Issin et al. emphasized that when evaluating femur and ankle alignment in knee osteoarthritis patients, the effect on neighbouring joints should be considered while managing such patients (23). For assessment of knee alignment, the hip-knee-ankle angle as measured on full-length weight-bearing radiographs in standing position is considered the gold standard (21,24,25). However, in general practice, standard anteroposterior weight-bearing radiographs are often used for assessment of knee deformity using the femorotibial angle (26).

Van Raaij et al. conducted a study to evaluate the usefulness of femorotibial angle in osteoarthritis patients in clinical settings (26). In their study, femorotibial angle assessment correlated well with hip-knee-ankle angle; however, they also documented poor inter-observer agreement and concluded that short knee radiographs cannot substitute full-length radiographs when accurate assessment of knee alignment is necessary (26). Similarly, Zampogna et al. commented that for accurate assessment of knee alignment, full-leg radiographs should be used (27). In a multicenter osteoarthritis study, Sheehy et al. also suggested the use of full-length radiographs for accurate assessment of knee alignment (28).

For ankle and hindfoot assessment, routine anteroposterior and lateral weight-bearing radiographs are used for evaluation of the ankle joint and hindfoot. However, superimposition of foot and ankle bones in these radiographs makes them inappropriate for assessment of hindfoot alignment (29). For this purpose, specialized views such as the hindfoot alignment view described by Saltzman and el-Khoury and the long axial view described by Cobey have been developed (30,31).

In a comparative study of long axial view and hindfoot alignment view for assessment of hindfoot alignment, Reilingh et al. demonstrated better inter-observer reliability with the long axial view and recommended its use for both clinical and research purposes (32). Xie et al. studied the effect of varus knee deformities on ankle alignment in patients with knee osteoarthritis and found significant correlation between ankle malalignment and varus knee deformity, though they suggested further studies for consolidation of these findings (33).

Despite this growing body of evidence, there remains a paucity of literature investigating the comprehensive correlation of knee alignment with ankle and hindfoot alignment specifically in patients with Grade IV osteoarthritis of the knee. Furthermore, the relationship between these alignment parameters and clinical severity measures has not been extensively studied. Understanding these relationships may have important implications for comprehensive management strategies, including surgical planning, orthotic interventions, and prognostic assessment. This study aims to address this gap by evaluating the correlation of knee alignment with ankle and hindfoot alignment and clinical severity in patients with Grade IV knee osteoarthritis.

MATERIALS AND METHODS

Study Design and Setting

This observational cross-sectional study was conducted at the Department of Physical Medicine and Rehabilitation, Vardhaman Mahavir Medical College and Safdarjung Hospital, New Delhi, over a period of 18 months from 2019 to 2021. The study protocol was approved by the Institutional Ethics Committee.

Sample Size Calculation

Sample size was calculated based on a previous study by Xie et al. (25), which observed a positive correlation between knee alignment and tibial anterior surface angle ($r=0.295$). With 80% power of study and 5% level of significance, the minimum required sample size was calculated as 88 patients. To reduce the margin of error, the total sample size was taken as 90 patients.

The formula used was: $n = [(Z\alpha + Z\beta)/C(r)]^2 + 3$

Where $Z\alpha$ is the value of Z at two-sided alpha error of 5%, $Z\beta$ is the value of Z at power of 80%, and $C(r) = 0.5 \times \ln[(1+r)/(1-r)]$

Inclusion Criteria

1. Patients diagnosed with primary knee osteoarthritis according to American College of Rheumatology (ACR) criteria (29)
2. Kellgren-Lawrence Grade IV osteoarthritis (30)
3. Age ≥ 18 years
4. Ability to provide informed consent

Exclusion Criteria

1. Previous surgery involving knee and/or ankle

2. Secondary osteoarthritis
3. History of injury to foot and/or knee that may compromise knee function
4. Nerve-related symptoms (radiculopathy)
5. Complex regional pain syndrome
6. Rheumatoid arthritis or other inflammatory arthritis
7. Diabetes mellitus
8. Local or systemic infection
9. Peripheral vascular disease
10. Metabolic diseases such as gout
11. Malignancy
12. Presence of other causes of knee pain
13. Pregnancy
14. Other deformities of the lower limb except varus-valgus knee

Patient Selection and Recruitment

Consecutive patients with knee osteoarthritis attending the Physical Medicine and Rehabilitation Department of Safdarjung Hospital who satisfied the inclusion and exclusion criteria were enrolled in the study after obtaining written informed consent. All participants were provided with a detailed patient information sheet in English and Hindi explaining the study objectives, procedures, risks, and benefits.

Radiological Assessment

Knee Alignment Assessment

Knee alignment was assessed using full-limb anteroposterior radiographs taken in a standing, weight-bearing position. The hip-knee-ankle (HKA) angle was measured and is formed by the intersection of the line connecting the centers of the femoral head and intercondylar notch with the line connecting the center of the surface of the talus and tips of tibial spine (18-20). This method represents the gold standard for assessment of knee alignment in osteoarthritis research.

Ankle and Hindfoot Alignment Assessment

Ankle and hindfoot alignment were evaluated using long axial view radiographs, which have been shown to have better inter-observer reliability compared to hindfoot alignment view (24). The following five radiological parameters were measured:

1. **Angle between mid-diaphyseal line of tibia and mid-diaphyseal line of calcaneus:** This angle reflects the overall hindfoot alignment in relation to the tibial axis.
2. **Tibiotalar angle:** Measured as the angle between the tibial anatomical axis and the talar dome, representing the ankle joint alignment in the coronal plane.
3. **Tibial anterior surface (TAS) angle:** Measured between the anterior cortical surface of the distal tibia and the articular surface of the tibial plafond.
4. **Talar tilt angle:** Measured as the angle between the superior articular surface of the talus and the tibial plafond, indicating talar positioning within the ankle mortise.
5. **Angle between ground surface and distal tibial plafond:** This angle represents the orientation of the ankle joint relative to the ground during weight-bearing.

All radiological measurements were performed by two independent observers blinded to the clinical assessment data to ensure reliability.

Clinical Assessment

Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC): The WOMAC index was used to assess patients with knee osteoarthritis using 24 parameters across three domains: pain (5 items), stiffness (2 items), and physical function (17 items) (26). Patients were instructed to consider both knees collectively and respond according to their experience during the previous 24 hours. Each item was scored on a 5-point Likert scale (0=none, 1=slight, 2=moderate, 3=severe, 4=extreme). The total score ranges from 0 to 96, with higher scores indicating greater disease severity. For the physical function subscale alone, the maximum score was 68 points.

Health Assessment Questionnaire (HAQ): The modified Health Assessment Questionnaire, adapted for the Indian scenario, was used to assess functional disability (27). The questionnaire includes 12 activities of daily living across 8 categories: dressing, arising, eating, walking, hygiene, reach, grip, and common activities. Each item was scored from 0 (without difficulty) to 3 (unable to do). Higher scores indicate greater functional disability.

Visual Analogue Scale (VAS): Pain intensity was assessed using a 100-mm Visual Analogue Scale (28). Patients were instructed to mark on the line between "no pain" and "pain as bad as it can be" to indicate their current pain level. The distance from the "no pain" end to the patient's mark was measured in millimetres, providing a score from 0 to 100.

Data Collection: All participants underwent a comprehensive clinical examination, including detailed history taking and physical examination of both knee joints. Demographic data, including age, sex, body mass index, occupation, and socioeconomic status, were recorded. Medical history, including duration of symptoms, previous treatments, and comorbidities, was documented. Laboratory investigations including haemoglobin, total leucocyte count, differential leucocyte count, erythrocyte sedimentation rate, rheumatoid factor, blood glucose, and serum uric acid levels were performed to rule out exclusion criteria.

Statistical Analysis: Categorical variables are presented as number and percentage (%), while continuous variables are presented as mean $\pm$ standard deviation (SD) and median. Normality of data was tested using the Kolmogorov-Smirnov test. For non-normally distributed data, non-parametric tests were applied.

The following statistical tests were used:

1. Quantitative variables were compared using unpaired t-test or Mann-Whitney U test (for non-normally distributed data) between groups
2. Qualitative variables were analysed using Chi-square test or Fisher's exact test
3. Pearson correlation coefficient or Spearman rank correlation coefficient (for non-parametric data) was used to assess correlations between quantitative variables

A p-value of <0.05 was considered statistically significant. Data were entered in Microsoft Excel spreadsheet, and analysis was performed using Statistical Package for Social Sciences (SPSS) version 21.0.

RESULTS

This observational cross-sectional study was conducted in the outpatient department of Physical Medicine and Rehabilitation, VMMC and Safdarjung Hospital, New Delhi, over 18 months. A total of 105 patients were screened, of which 77 patients satisfying the inclusion criteria were enrolled after written informed consent. Twenty-eight patients were excluded from the study.

Demographic Characteristics

Age Distribution

The age of enrolled patients ranged from 40 to 78 years, with a mean age of 59.98 ± 8.44 years (Table 1). Most patients (55.8%) were in the 60-69 age group, followed by 16.9% in the 50-59 age group, 14.3% in the 70-79 age group, and 13.0% in the 40-49 age group.

Table 1: Demographic Characteristics of Study Participants (n=77)

Variable	Category	n (%) / Mean $\pm$ SD
Age (years)	Mean $\pm$ SD	59.98 $\pm$ 8.44
	Range	40-78
	40-49 years	10 (13.0%)
	50-59 years	13 (16.9%)
	60-69 years	43 (55.8%)
	70-79 years	11 (14.3%)
Gender	Female	48 (62.3%)
	Male	29 (37.7%)
Education	Illiterate	42 (54.5%)
	Primary	24 (31.2%)
	Middle	3 (3.9%)
	Intermediate	8 (10.4%)
Disease Duration	Mean $\pm$ SD (years)	6.67 $\pm$ 2.86
	Range	2-15 years
	2-5 years	31 (40.3%)
	6-10 years	38 (49.3%)
	11-15 years	8 (10.4%)

Gender Distribution

Among the 77 participants, 48 (62.3%) were female and 29 (37.7%) were male, showing a female preponderance with a female-to-male ratio of approximately 1.7:1.

Educational Status

The majority of participants (54.5%) were illiterate, while 31.2% had primary education, 10.4% had intermediate education, and only 3.9% had middle school education.

Disease Duration

The mean disease duration was 6.67 ± 2.86 years, ranging from 2 to 15 years. Nearly half of the patients (49.3%) had disease duration between 6-10 years, followed by 40.3% with 2-5 years duration, and 10.4% with 11-15 years duration.

Knee Alignment and Ankle-Hindfoot Alignment Measurements

Bilateral Lower Limb Measurements

Radiological measurements were obtained from both lower limbs of all 77 patients, yielding 154 limb measurements. Table 2 presents the mean values for knee alignment (HKA angle) and five ankle-hindfoot alignment parameters.

Table 2: Knee and Ankle-Hindfoot Alignment Measurements (n=154 limbs)

Angle	Right Limb (n=77) Mean $\pm$ SD	Left Limb (n=77) Mean $\pm$ SD	Both Limbs (n=154) Mean $\pm$ SD	Z-value	P-value
HKA	12.99 ± 4.06	13.49 ± 3.78	13.24 ± 3.92	0.622	0.534
ADTC	5.81 ± 2.37	5.35 ± 2.56	5.58 ± 2.47	2.457	0.014*
TTA	92.17 ± 5.23	91.12 ± 6.28	91.64 ± 5.78	3.182	0.001**
TAS	90.60 ± 5.43	89.47 ± 6.23	90.03 ± 5.85	3.740	0.000**
TT	1.57 ± 0.68	1.70 ± 0.81	1.64 ± 0.75	1.040	0.298
GP	6.01 ± 1.50	5.77 ± 1.74	5.89 ± 1.62	1.575	0.115

* $P < 0.05$; ** $P < 0.01$ HKA: Hip-Knee-Ankle angle; ADTC: Angle between mid-diaphyseal line of tibia and calcaneus;

TTA: Tibiotalar angle; TAS: Tibial anterior surface angle; TT: Talar tilt angle; GP: Ground-plafond angle

The mean HKA angle for all limbs was 13.24 ± 3.92 degrees, indicating varus malalignment in the study population. When comparing right and left limbs, no significant differences were observed in HKA ($p=0.534$), TT ($p=0.298$), and GP ($p=0.115$) angles. However, statistically significant differences were found between right and left limbs for ADTC ($p=0.014$), TTA ($p=0.001$), and TAS ($p=0.000$) angles.

Correlation of Knee Alignment with Ankle and Hindfoot Alignment

Spearman rank correlation analysis was performed to assess the relationship between knee alignment (HKA angle) and various ankle-hindfoot alignment parameters. The results are presented in Table 3.

Table 3: Correlation of Knee Alignment (HKA) with Ankle and Hindfoot Alignment Parameters (n=154 limbs)

Parameter	Correlation Coefficient (r)	P-value	Interpretation
ADTC	0.262	0.001**	Weak positive correlation
TTA	0.330	0.000**	Moderate positive correlation
TAS	0.343	0.000**	Moderate positive correlation
TT	-0.042	0.606	No significant correlation
GP	0.421	0.000**	Moderate positive correlation

** $P < 0.01$ ADTC: Angle between mid-diaphyseal line of tibia and calcaneus; TTA: Tibiotalar angle; TAS: Tibial anterior surface angle; TT: Talar tilt angle; GP: Ground-plafond angle

The HKA angle showed statistically significant positive correlations with four out of five ankle-hindfoot alignment parameters:

- **ADTC** ($r=0.262$, $p=0.001$): weak positive correlation
- **TTA** ($r=0.330$, $p<0.001$): moderate positive correlation
- **TAS** ($r=0.343$, $p<0.001$): moderate positive correlation
- **GP** ($r=0.421$, $p<0.001$): moderate positive correlation, representing the strongest association among all parameters

However, TT angle showed a weak negative correlation with HKA ($r=-0.042$), which was not statistically significant ($p=0.606$).

Clinical Severity Assessment

Disease severity was assessed using three validated instruments: the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Health Assessment Questionnaire (HAQ), and Visual Analogue Scale (VAS) for pain. The mean scores are presented in Table 4.

Table 4: Clinical Severity Scores (n=77 patients)

Assessment Tool	Mean $\pm$ SD	Range	Maximum Possible Score
WOMAC	64.52 ± 5.45	-	68

HAQ	16.95 ± 3.18	-	24
VAS	6.12 ± 0.54	-	7

The WOMAC score averaged 64.52 ± 5.45 out of a maximum of 68, indicating severe functional impairment. The mean HAQ score was 16.95 ± 3.18 out of 24, reflecting substantial disability in activities of daily living. The VAS pain score averaged 6.12 ± 0.54 out of 7, demonstrating severe pain intensity in the study population.

Correlation of Knee Alignment with Clinical Severity

Spearman rank correlation analysis revealed significant positive correlations between knee alignment (HKA angle) and all three clinical severity parameters, as shown in Table 5.

Table 5: Correlation of Knee Alignment (HKA) with Clinical Severity Parameters (n=154 limbs)

Clinical Parameter	Correlation Coefficient (r)	P-value	Interpretation
VAS	0.279	0.000**	Weak positive correlation
WOMAC	0.579	0.000**	Moderate positive correlation
HAQ	0.524	0.000**	Moderate positive correlation

**P<0.001 VAS: Visual Analogue Scale; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; HAQ: Health Assessment Questionnaire

All correlations were statistically highly significant ($p<0.001$):

- **VAS:** weak positive correlation ($r=0.279$)
- **WOMAC:** moderate positive correlation ($r=0.579$), representing the strongest association
- **HAQ:** moderate positive correlation ($r=0.524$)

These findings indicate that increased varus knee deformity (higher HKA angle) is associated with greater pain intensity, worse functional impairment, and higher disability in activities of daily living.

DISCUSSION

Osteoarthritis is a chronic, progressive degenerative disorder that predominantly affects weight-bearing joints, with the knee being one of the most commonly involved sites. This observational cross-sectional study investigated the correlation of knee alignment with ankle and hindfoot alignment, as well as clinical severity, in 77 patients with Grade IV knee osteoarthritis. The findings provide valuable insights into the biomechanical interrelationships within the lower extremity and their impact on disease severity.

The mean age of participants in our study was 59.98 ± 8.44 years, with the majority (55.8%) in the 60-69 age group. This age distribution is consistent with the established epidemiology of osteoarthritis, which shows increasing prevalence with advancing age. The preponderance of female participants (62.3%) in our study aligns closely with findings from previous research. Xie et al. reported 70% female participation in their study on varus knee deformities and ankle alignment, while Bushmakina et al. and Sadosky et al. reported 63.1% and 61.7% female participants respectively in studies on patient-reported disease severity in osteoarthritis. This gender disparity reflects the well-documented higher prevalence of knee osteoarthritis in women, particularly after menopause, which may be attributed to hormonal changes, biomechanical factors, and anatomical differences.

The high proportion of illiterate participants (54.5%) in our study is noteworthy and consistent with findings by Venkatachalam et al. in their study on knee osteoarthritis prevalence in rural Tamil Nadu. This demographic characteristic may reflect healthcare-seeking patterns, with lower socioeconomic status and limited education potentially delaying medical consultation until advanced disease stages. The mean disease duration of 6.67 ± 2.86 years suggests that most patients had longstanding disease by the time of enrolment, which is typical for Grade IV osteoarthritis.

The mean HKA angle in our study was 13.24 ± 3.92 degrees, indicating substantial varus malalignment in this Grade IV osteoarthritis population. This finding is consistent with the well-established pattern of medial compartment predominance in knee osteoarthritis. The medial compartment bears approximately 70% of body weight during normal gait, making it more susceptible to degenerative changes compared to the lateral and patellofemoral compartments.

When comparing bilateral measurements, we observed no significant differences in HKA, TT, and GP angles between right and left limbs. However, statistically significant differences were noted for ADTC, TTA, and TAS angles. These asymmetries may reflect differences in limb dominance, weight-bearing patterns, or disease progression between limbs. The clinical significance of these bilateral differences warrants further investigation.

A key finding of our study was the demonstration of significant positive correlations between knee alignment (HKA angle) and most ankle-hindfoot alignment parameters. The GP angle showed the strongest correlation ($r=0.421$,

$p < 0.001$), followed by TAS ($r = 0.343$, $p < 0.001$), TTA ($r = 0.330$, $p < 0.001$), and ADTC ($r = 0.262$, $p = 0.001$). These correlations suggest that progressive varus deformity at the knee is associated with compensatory changes in ankle and hindfoot alignment.

Our findings are partially consistent with the study by Xie et al., who reported a significant positive correlation between HKA and GP angle, similar to our results. However, unlike Xie et al., who found TTA correlation to be non-significant overall (though significant in females), we observed significant correlations for TTA across our entire cohort. Additionally, Xie et al. reported significant TAS correlation only in females, whereas our study demonstrated significant TAS correlation in the combined population. These discrepancies may be attributed to differences in study populations, sample sizes, or methodological approaches.

The TT angle in our study showed a weak negative correlation with HKA ($r = -0.042$, $p = 0.606$), which was not statistically significant. This finding aligns with Xie et al.'s observation of negative correlation, though they reported significance in their female subgroup. The negative correlation, though weak, may suggest a compensatory mechanism where the talus tilts in the opposite direction to the varus knee deformity, potentially representing an adaptive response to maintain overall lower limb balance.

The novel contribution of our study lies in the assessment of ADTC angle, which to our knowledge has not been previously reported in the literature examining the relationship between knee and ankle-hindfoot alignment. The significant positive correlation ($r = 0.262$, $p = 0.001$) indicates that varus knee deformity is associated with altered tibio-calcaneal relationships, further supporting the concept of lower extremity alignment as an integrated biomechanical system.

The observed correlations can be understood through biomechanical principles governing lower extremity function (6,8). The long-term pathological processes in severe knee osteoarthritis alter the mechanical axis of the lower limb, leading to compensatory changes in distal joints (15,16,17). The rotational coupling between the hindfoot and tibia means that knee deformities inevitably affect ankle and hindfoot alignment (21,32). As the knee develops progressive varus deformity, ground reaction forces are redistributed, potentially accelerating degenerative changes in the ankle joint (17,19).

Zhang et al. (15) described how varus knee alignment creates transverse shearing forces, with the femoral condyle shifting medially during gait due to the slope of the medial tibial plateau. This biomechanical alteration extends distally, affecting ankle joint mechanics and hindfoot positioning. The strong correlation between HKA and GP angle observed in our study ($r = 0.421$) suggests that the orientation of the ankle joint relative to the ground surface is particularly susceptible to proximal knee deformities, likely affecting weight distribution during stance and gait (15,33).

Lafeber et al. (52) and Tiku et al. (53) have discussed the potential for cartilage regeneration through joint unloading and distraction. Similarly, Koshino et al. (54) documented regeneration of articular cartilage after high tibial valgus osteotomy for medial compartment osteoarthritis, suggesting that realignment procedures may have beneficial effects on cartilage health. These findings support the importance of addressing malalignment early in the disease process to potentially slow progression (9,12).

The clinical severity assessment revealed severe disease burden in our study population, with mean WOMAC score of 64.52 ± 5.45 out of 68, HAQ score of 16.95 ± 3.18 out of 24, and VAS pain score of 6.12 ± 0.54 out of 7. Our WOMAC score is remarkably consistent with findings by Sathiyarayanan et al. (58), who reported a mean WOMAC score of 64.40 ± 15.2 in their screening study for knee osteoarthritis.

The significant positive correlations between HKA angle and all three clinical severity parameters (VAS: $r = 0.279$, $p < 0.001$; WOMAC: $r = 0.579$, $p < 0.001$; HAQ: $r = 0.524$, $p < 0.001$) provide compelling evidence that knee malalignment is not merely a radiological finding but has substantial functional and symptomatic implications (9,24,25). The strongest correlation was observed with WOMAC ($r = 0.579$), suggesting that knee alignment particularly impacts the specific functional activities assessed by this osteoarthritis-specific instrument, including walking, stair climbing, and other weight-bearing activities (24,58).

These findings corroborate those of Sharma et al. (9), who demonstrated that knee alignment plays a significant role in disease progression and functional decline in knee osteoarthritis, with increasing varus malalignment associated with greater pain and functional deterioration. Similarly, Singh (59) reported increasing WOMAC scores with advancing Kellgren-Lawrence grades, supporting the relationship between structural severity and symptomatic burden.

The association between quadriceps weakness and knee osteoarthritis, as documented by Slemenda et al. (47), further supports the complex interplay between biomechanical factors and clinical outcomes. Reduced muscle strength may both result from and contribute to malalignment and pain (47,48). Steultjens et al. (48) found that limited range of motion,

particularly in knee flexion, was a significant determinant of disability in osteoarthritis patients, consistent with our findings of severe functional impairment.

The relationship between pain mechanisms and structural changes in osteoarthritis has been elucidated by several investigators (44,45,46). Schaible et al. (44) described peripheral and central mechanisms of pain generation in arthritis, while Muratovic et al. (45) demonstrated associations between bone marrow lesions and severity of osteochondral degeneration. Hunter et al. (46) provided comprehensive insights into the genesis of osteoarthritis pain, noting that pain may arise from multiple sources including bone, synovium, and periarticular structures. Our findings of high VAS scores (6.12 ± 0.54) correlated with alignment parameters suggest that mechanical factors contribute significantly to the pain experience in severe knee osteoarthritis (9,44,46).

Study Strengths and Limitations

Strengths:

1. Use of gold-standard full-length weight-bearing radiographs for knee alignment assessment, as recommended by multiple investigators.
2. Comprehensive evaluation of multiple ankle-hindfoot alignment parameters using validated radiographic techniques.
3. Assessment of both radiological and clinical outcomes using validated instruments (WOMAC, HAQ, VAS)
4. Novel evaluation of ADTC angle not previously reported in literature
5. Bilateral assessment allowing comparison between limbs (154 limb measurements)

Limitations:

1. Cross-sectional design precludes establishment of causality or temporal relationships, as noted in similar studies.
2. Reduced sample size (77 instead of planned 90) due to COVID-19 pandemic, though statistical power remained adequate for detecting significant correlations.
3. Single-center study may limit generalizability to other populations with different demographic characteristics.
4. No comparison group without osteoarthritis or with milder disease grades to establish baseline alignment relationships.
5. Inter-observer and intra-observer reliability of radiological measurements not formally assessed, though standardized measurement techniques were employed.
6. Potential selection bias as only patients attending tertiary care center were included.
7. No longitudinal follow-up to assess progression of alignment changes over time.
8. Did not evaluate gait parameters or dynamic biomechanical factors that may influence the observed relationships.

CONCLUSION

This observational cross-sectional study provides compelling evidence for significant correlations between knee alignment and both ankle-hindfoot alignment and clinical severity in patients with Grade IV osteoarthritis of the knee.

This study establishes clear evidence that knee alignment in Grade IV osteoarthritis is significantly correlated with both ankle-hindfoot alignment and clinical severity. These findings underscore the importance of viewing the lower extremity as an integrated biomechanical unit rather than isolated joints. Clinicians managing severe knee osteoarthritis should consider evaluating and addressing ankle and hindfoot alignment as part of comprehensive care. The strong associations between alignment parameters and functional outcomes suggest that HKA angle may serve as a valuable prognostic indicator for disease severity and treatment planning.

However, the cross-sectional nature of this study limits conclusions about causality and progression. Future longitudinal studies with larger sample sizes are warranted to further consolidate these findings, establish temporal relationships, evaluate the impact of interventions on distal alignment, and develop comprehensive management strategies addressing the entire lower extremity kinetic chain in patients with severe knee osteoarthritis.

ACKNOWLEDGMENTS

The authors acknowledge the support of the Department of Physical Medicine and Rehabilitation and the Department of Radiology at Vardhaman Mahavir Medical College and Safdarjung Hospital, New Delhi. We thank all patients who participated in this study.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

FUNDING

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

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