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The Mechanical Lateral Distal Femoral Angle in Thai Patients With Varus Knee Osteoarthritis

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Purpose: Varus deformity is commonly observed in knee osteoarthritis (OA) and involves medial compartment degeneration, bone morphologic changes, soft tissue balance, and may complicate mechanical alignment during total knee arthroplasty (TKA), especially involving conventional alignment techniques. We evaluated the distribution of mechanical lateral distal femoral angle (mLDFA) and its association with coronal alignment parameters in Thai patients with varus knee OA to improve preoperative planning.

Methods: Patients with varus knee OA who underwent preoperative orthoroentgenographic imaging between 2020 and 2023 were retrospectively stratified into three mLDFA-based groups (<90° [A], 90° [B], >90° [C]) to compare differences in hip-knee-ankle angle (HKAA), joint line convergence angle (JLCA), and mechanically aligned-anatomical angle (MA-AA).

Results: mLDFA prevalence was determined in 444 patients (Group-wise: A=56.3%; B=28.7%; C=14.9%). Group A had smaller MA-AA values (5.38° ± 1.44°) compared with Group C (6.74° ± 1.69°, $p < 0.001$). Increased mLDFA values were associated with reduced HKAA values, while mLDFA values positively correlated with those of MA-AA. The mean JLCA value was significantly higher in patients with HKAA <170° compared with those with HKAA ≥170° (7.14° vs. 3.83°, $p < 0.001$). A JLCA value ≥10° was more prevalent in patients with HKAA <170° (18.2%) than in those with HKAA >170° (0.35%).

Conclusions: Increased mLDFA and MA-AA values were associated with more severe varus deformity (showed reduced HKAA values), indicating a need to individualize distal femoral valgus correction during TKA for patients with severe varus deformity. Preoperative mLDFA assessment may optimize alignment and surgical outcomes.

Keywords: Varus deformity osteoarthritis, mechanical lateral distal femoral angle, hip-knee-ankle angle, joint line convergence angle

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The most common surgical intervention for end-stage knee osteoarthritis is total knee arthroplasty (TKA) which provides considerable pain relief and improves functional outcomes. Nonetheless, the level of patient satisfaction is unstable, and researchers have indicated that the satisfaction rate is approximately 83%[6]. Restoration of the lower limb mechanical axis to a position within 3° of neutral mechanical alignment is one of the critical factors that can lead to better outcomes because it is linked to a reduced probability of early loosening and better success of prosthesis survival(1-5).

TKA based on mechanical alignment (MA) is still widely used at many centers with an aim to recreate the neutral mechanical axis. Kinematic alignment (KA), on the other hand, also aims to reproduce the native joint lines of the patient and the balance of their ligaments, instead of placing a predetermined neutral axis. Computer-assisted techniques, including navigation and robotics, are key factors that have contributed to the improved precision of surgery and can be implemented during both MA and KA procedures as they provide the ability to re-shape bones of the distal part of the femur and the proximal part of the tibia with more precise cuts(20,21). However, the clinical outcomes of alignment strategies vary. As an illustration, Shelton et al. reported that patients who received KA were more satisfied (92 for KA vs. 83 for MA) based on Forgotten Joint Score (FJS) and Oxford Knee Score (OKS)(6). Similarly, de Grave et al. discovered that patients receiving restricted inverse kinematic alignment (iKA) were more satisfied than those who received adjusted mechanical alignment (aMA)(8). Patient satisfaction was primarily based on pain relief (72-86% and functional improvement (70-84%)(7).

In a previous study, Songkiat et al. reported that 21% of Thai patients with varus knee deformity following primary knee osteoarthritis (OA) presented with femoral bowing post-arthritis(9). Yu-Hsien et al. classified coronal knee alignment into five groups: 1) neutral alignment with normal joint line obliquity, 2) neutral alignment with a high degree of joint line obliquity, 3) genu varus knee with varus deformity of the tibia, 4) genu varus knee with varus deformity of both the tibia and femur, and 5) genu valgus knee. They found that patients with genu varus knees (groups 3 and 4) exhibited more severe femoral bowing than those in the neutral alignment groups (groups 1 and 2). Therefore, caution is advised when using an intramedullary guide for distal femoral resection in such cases because of the inherent imprecision in patients with severe femoral bowing(10).

This study aimed to evaluate the magnitude and prevalence of coronal knee alignment in Thai patients with OA and varus knee deformity. Specifically, we assessed the angulation of the distal femoral and femoral mechanical axes that are critical parameters for cutting of the distal femur during surgery, using an intramedullary cutting guide. Additionally, we evaluated the correlation between the mechanical lateral distal femoral angle (mLDFA) and other coronal knee alignment measures, such as the mechanically aligned-anatomical angle (MA-AA), joint line convergence angle (JLCA), and hip-knee-ankle angle (HKAA).

METHODS

This study was approved by our institutional ethics committee. Medical records and preoperative full-length standing radiographs (orthoroentgenograms) obtained between 2020 and 2023 were retrospectively reviewed. Demographic data (age and sex) and radiographic measurements, including mLDFA, MA-AA, JLCA, and HKAA were collected for all eligible patients.

Inclusion and Exclusion Criteria

The study sample included 444 patients with primary knee OA who showed varus deformity and underwent preoperative full-length standing radiography (orthoroentgenography). This was done only on patients whose Kellgren-Lawrence grade was 3 and above to ensure that they had radiographically advanced OA to be evaluated in surgical terms. Patients were excluded if they had conditions that could confound coronal alignment measurement, such as:

- Secondary OA (including post-traumatic OA, rheumatoid arthritis or infection).
- History of limb alignment (history of femoral or tibial fracture).
- Past ligament repair or other significant knee surgeries that changed the original alignment.
- Extra-articular femoral or tibial deformities (e.g., malunion, congenital deformities) that may affect the reliability of measuring these variables.

Radiographic Measurements

Variables related to lower limb coronal alignment were measured as follows (as previously described by Yu-Hsien et al[10]):

mLDFA: The lateral angle between the mechanical axis of the femur and the distal femoral joint line is defined as the connection between the lowest points of the medial and lateral femoral condyles.

MA-AA: The angle between the mechanical and anatomical axes of the femur.

JLCA: The angle between the joint line of the distal femur and proximal tibia.

HKAA: The angle between the mechanical axis of the femur and tibia, indicating either varus or valgus knee alignment (Fig. 1).

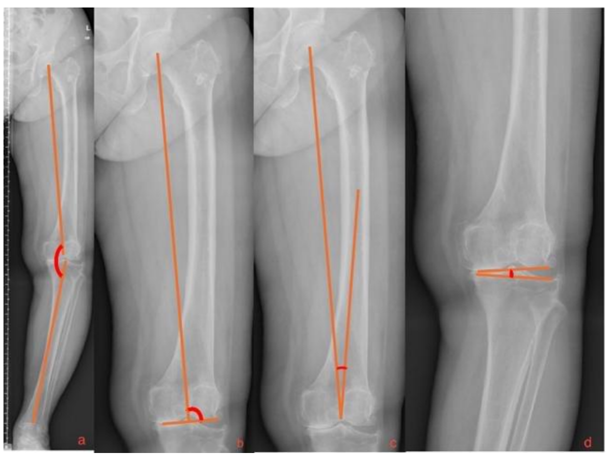

Fig. 1 Measurements of coronal alignment parameters. The four angles were defined as follows: **a)** Hip-knee-ankle angle (HKAA)—the angle between the mechanical axis of the femur and the mechanical axis of the tibia; **b)** Mechanical lateral distal femoral angle (mLDFA)—the lateral angle between the mechanical axis of the femur and the distal femur joint line, which defines the connection of the lowest points of the medial and lateral femoral condyle; **c)** Mechanically aligned-anatomical angle (MA-AA): the angle between the mechanical and anatomical axes of the femur; **d)** Joint line convergence angle (JLCA)—the angle between the knee joint line of the distal femur and proximal tibia.

Radiographic Quality Control

All radiographs were acquired in the form of standardized full-length standing radiographs (orthoroentgenograms) with the patients standing upright and their knees straight. The feet were placed such that the patellae faced forward to reduce the internal or external rotations of the tibia and femur. Radiographs with apparent malrotation, flexion contracture, or insufficient visualization of anatomical landmarks were eliminated and repeated before the measurement was completed.

All measurements were performed using SYNAPSE® (Version 1.0.0.2, Fujifilm Medical Systems, Tokyo, Japan), a medical imaging software used for digital radiograph analysis by an orthopedic surgeon specializing in hip and knee arthroplasty with over 9 years of experience. To ensure reliability, each measurement was independently repeated twice by two observers.

Group Categorization

For analysis, the patients were categorized based on coronal alignment parameters. The mLDFA value was used to categorize study participants into three groups (Group A: mLDFA < 90°; Group B: mLDFA = 90°; Group C: mLDFA > 90°). The HKAA value was categorized into two classes, namely, HKAA ≥170° (mild varus knee position) and HKAA < 170° (severe varus knee position). The JLCA value was categorized into two classes: JLCA < 10° and JLCA ≥10°.

The mLDFA value was used to divide the study participants into three groups:

Group A: mLDFA < 90°;

Group B: mLDFA = 90°; and

Group C: mLDFA > 90°.

The HKAA value was used to divide the cohort into two groups:

HKAA ≥ 170° (mild varus knee alignment) and

HKAA < 170° (severe varus knee alignment).

The JLCA value was used to divide the study cohort into two groups:

JLCA < 10°

JLCA ≥ 10°

Statistical Analysis

The continuous variables, such as age and radiographic measurements, were used as mean ± standard deviation (SD) while the categorical variables, such as sex and subgroups of alignment, were shown as numbers and percentages. One-way analysis of variance was used to compare the mean age, mLDFA, and MA-AA of each mLDFA group. The Chi-squared test was applied to test the distribution of sex, HKAA groups (HKAA < 170° and HKAA ≥ 170°), and JLCA groups (JLCA < 10° and JLCA ≥ 10°) of each mLDFA group. Independent t-tests were used to compare the mean values of JLCA and MA-AA in the HKAA groups. The Chi-squared test was used to test the prevalence of JLCA subgroups across the HKAA groups. Pearson's correlation test was used to analyze correlations between mLDFA and HKAA, JLCA, and MA-AA.

RESULTS

A total of 444 patients participated in this study. There was no statistically significant difference in the mean age between the mLDFA groups (p = 0.663), and most patients were women (Table 2). Groups A (mLDFA <90°), B (mLDFA =90°), and C (mLDFA >90°) revealed percentage distributions of 56.3%, 28.7%, and 14.9%, respectively.

The mean mLDFA value was also markedly different at the group level wherein Group A had a mean value of 86.9° and that of Group C was 92.1°. The MA-AA value also improved steadily from Group A (5.38°) to Group C (6.74°) (p < 0.001) (Table 1).

There was an increase in the proportion of patients with severe varus alignment (HKAA <170°) among the mLDFA groups, with 23.3% in Group A and 57.6% in Group C, (p < 0.001). The difference in JLCA values between the groups was not significant (p = 0.211) (Table 2). There were a total of 154 (34.8%) patients with HKAA values below 170° and 288 (65.2%) patients with HKAA values <170° (34.8% and 65.2%, respectively).

Table 1 The mean of mLDFA, Age, MA-AA in each group of mLDFA.

	mLDFA			p-value
	<90° 249 (56.3%)	**90° 127 (28.7%)**	**>90° 66 (14.9%)**	
mLDFA (mean ± SD)	86.9±2.0	90	92.1±1.17	-
Age (mean ± SD)	69.3±7.53	70.04±8.31	69.3±8.12	0.663
MA-AA (mean ± SD)	5.38±1.44	6.50±1.34	6.74±1.69	<0.001

Table 2 The prevalence of Sex, HKAA, JLCA in each group of mLDFA.

	mLDFA			p-value
	<90° 249 (56.3%)	**90° 127 (28.7%)**	**>90° 66 (14.9%)**	
Sex n (%)				0.094
Men	30 (12.1)	23 (18.1)	14 (21.2)	
Women	219 (88.0)	104 (81.9)	52 (78.8)	
HKAA				<0.001
< 170°	58 (23.3)	58 (45.7)	38 (57.6)	
≥ 170°	191 (76.7)	69 (54.3)	28 (42.4)	
JLCA				0.211
<10°	237 (95.2)	115 (90.6)	61 (92.4)	
≥10°	12 (4.82)	12 (9.45)	5 (7.58)	

Patients with severe varus (HKAA <170°) had a better JLCA (7.14° vs. 3.83°, p < 0.001) and MA-AA value (6.58° vs. 5.55°, p < 0.001). A JLCA value ≥10° was found in 18.2% of this subgroup as opposed to 0.35% in the mild varus group (Tables 3 and 4).

Correlation analysis showed that mLDFA values were negatively correlated with HKAA values (r = -0.366, p < 0.001) and positively correlated with MA-AA values (r = 0.342, p < 0.001). The mLDFA and JLCA values did not show any significant correlation (r = 0.083, p = 0.082) (Table 5).

Table 3 Prevalence and mean values of JLCA in each HKAA group.

HKAA	<170° (n=154, 34.8%)	≥170° (n=288, 65.2%)	p-value
JLCA (mean ± SD)	7.14 ± 2.49	3.83 ± 1.99	<0.001
JLCA < 10°	126 (81.8%)	287 (99.7%)	<0.001
JLCA ≥ 10°	28 (18.2%)	1 (0.35%)	<0.001

Table 4 Mean values of MA-AA in each HKAA group.

HKAA	<170° (n=154, 34.8%)	≥170° (n=288, 65.2%)	p-value
MA-AA (mean ± SD)	6.58 ± 1.47	5.55 ± 1.51	<0.001

Correlation Analysis

Pearson's correlation analysis revealed significant correlations between mLDFA values and other knee-axis parameters. The correlation between mLDFA and HKAA values was -0.366, and that between mLDFA and MA-AA values was 0.342, both with statistically significant differences (p < 0.001). The correlation between mLDFA and JLCA values was 0.083, which was not statistically significant (p = 0.082) (Table 5).

Table 5 The correlation between HKAA, JLCA, MA-AA to mLDFA.

	mLDFA	
	Pearson Correlation (r)	p-value
HKAA	-0.366	<0.001
JLCA	0.083	0.082
MA-AA	0.342	<0.001

DISCUSSION

The primary findings of the present study involved measuring the distribution of mLDFA values and their correlation with various coronal alignment parameters (HKAA, JLCA, and MA-AA). We found that mLDFA values varied significantly, with >50% of patients showing mLDFA values <90° and significant correlations with MA-AA and HKAA values, but not with JLCA values. These data show that femoral bowing plays a very important role in determining the overall coronal alignment, which has a direct surgical implication for TKA.

Relation to the Coronal Plane Alignment of the Knee (CPAK) Framework

The CPAK classification is a combination of constitutional limb alignment (quantified as arithmetic HKA [aHKA]) and joint line orientation (JLO) to describe coronal phenotypes. Although CPAK was not directly quoted in this study, the parameters we measured are the approximations of its components.

- Constitutional limb alignment (aHKA analog): Our HKAA stratification (≥170° vs <170°) reflects severity of varus alignment. The mLDFA groups grew steadily in terms of severe varus, indicating that bowing of the femur was directly related to global limb malalignment.
- JLO analog: JLCA is not identical to JLO but provides related information. Patients with severe varus showed significantly higher JLCA values (7.1° vs 3.8°) and a greater proportion with JLCA values ≥10%. This subgroup showed significant

convergence of joint lines, similar to the CPAK phenotypes that have oblique joint lines.

- Localization of deformity: The positive correlation between mLDFA and MA-AA values indicates the contribution of the femur to malalignment that is complemented by CPAK at the limb level and offers useful details regarding surgery planning.

The combination of these relationships suggests that a large proportion of patients with varus OA in Thailand would cluster around the CPAK phenotypes characterized by constitutional varus, with a fraction also exhibiting joint line obliquity. These findings advocate for the customization of alignment strategies instead of applying neutral mechanical alignment everywhere.

Surgical Implications

The direct implications of these findings are for preoperative planning and decision-making during surgery. In patients with a high MA-AA value, the valgus angle back-set on the intramedullary femoral guides can be reduced by surgeons to prevent accidental over-correction. Correspondingly, high knee JLCA values can be potentially harmful with an excessive enforced neutrality that highlights the importance of tailoring resection of the tibial and balancing soft tissues. Finally, since 85% of the knees we analyzed displayed mLDFA values ≤90°, surgeons must expect intramedullary cutting blocks to be seated medially first; lateral seating of these should be considered a red flag signaling abnormal anatomy and inadvertent introduction of valgus. These real-life examples demonstrate how the main findings of this study can be used to educate and improve surgical practice in TKA.

Role of Enabling Technologies

Reductions in alignment outliers have been observed in navigation, robotics, and patient-specific instrumentation[11-16]. These instruments are especially useful in identifying CPAK-like phenotypes associated with bowing of the femur and convergence along the accessory line, where minor, well-calculated corrections of the femoral valgus angle, tibial excision, and gap balancing are necessary. The use of technology to accomplish this will allow phenotype-aware alignment, while avoiding excessive correction.

Alignment Targets and Clinical Outcomes

Although the life of implants has been linked to the restoration of the mechanical axis within ~3° of the neutral value [17-19], increasing evidence points to the importance of selective individualization. We believe that our data indicate that alignment near the native state, such as applied with care to ensure balanced loading and tracking of the patella, may be the best way to improve patient satisfaction and survivorship with constitutional varus, in addition to increased JLCA. CPAK is one of the frameworks that can be beneficial for identifying such patients and supporting the decision to deviate from neutrality.

Strengths and Limitations

The strengths of this study are that it had a large cohort of full-length standing radiographs that were standardized with clear quality control, and reproducible measures that were acquired by experienced observers. Nevertheless, this study had several limitations that must be recognized. First, direct CPAK was not calculated because the medial proximal tibial angle and true joint line orientation to the floor were not provided. The JLCA only provides an indirect surrogate for JLO. Second, the retrospective study design and lack of intra- and postoperative outcomes made it impossible to conclude how such alignment patterns could be translated into clinical outcomes. Future prospective research studies should involve the entire CPAK dataset, soft-tissue laxity characterization, and a determination of whether patient-centered alignment strategies can increase patient-reported outcomes and implant survival.

CONCLUSIONS

This study found that in patients with varus knee deformity following OA, there was a significant correlation between increased mLDFA and elevated MA-AA values. In cases of severe varus knee deformity, careful preoperative radiographic planning is essential to avoid excessive valgus alignment, particularly when using conventional intramedullary guide instruments for TKA. A preoperative evaluation of the MA-AA value is crucial for an accurate setting of the intramedullary guide during distal femoral bone cutting. In such cases, reducing the valgus setting of the intramedullary guide to values similar to the combined mLDFA and MA-AA values may be beneficial.

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