УДК 616.728.3-002.77-073.7(045)

DOI: http://dx.doi.org/10.15674/0030-59872025453-62

# Radiographic features of knee osteoarthritis in the lateral view depending on joint line obliquity

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*Objective. To evaluate the radiographic features of sagittal knee joint morphology in osteoarthritis, taking into account the joint line obliquity determined using an original method (mJLO). Methods. 62 lateral knee radiographs of 45 patients with medial knee osteoarthritis were analyzed. The following radiographic parameters were assessed: posterior distal femoral angle (PDFA); posterior condylar offset ratio (PCOR); posterior tibial slope (PTS); tuberosity-modified tibial slope (TMTS); and tibial tuberosity inflection angle (TTIA). The mJLO was calculated as aMPTA + aLDFA + 6°. Values of mJLO < 177° were defined as apex distal (AD), 177°–183° as apex neutral (AN), and > 183° as apex proximal (AP). Statistical significance was defined as p ≤ 0.05. Results. AD was found in 43 patients (69.35 %), AN in 16 (25.81 %), and AP in 3 (4.84 %). Higher mJLO values and more proximal joint line orientation were associated with lower PDFA (τ = –0.25, p = 0.004) and PCOR (τ = –0.22, p = 0.01). Patients with PDFA > 88° had significantly higher odds of AD (OR = 3.63; CI: 1.20–12.33; p = 0.02), as did those with PTS > 8° (OR = 5.22; CI: 1.65–19.40; p = 0.004). Conversely, AD was less likely in patients with PDFA < 78° (OR = 0.08; CI: 0.01–0.34; p = 0.0005) and PTS 3°–8° (OR = 0.25; CI: 0.07–0.76; p = 0.01). Patients with PTS > 8° had a lower odds of AN (OR = 0.28; CI: 0.07–0.90; p = 0.03). Significantly higher odds of AP were observed in individuals with PDFA < 78° (OR = 49.00; CI: 4.17–6846.81; p = 0.001) and PCOR < 0.44 (OR = 11.67; CI: 1.06–1596.60; p = 0.04), whereas PCOR > 0.44 decreased the likelihood of this obliquity type (OR = 0.09; CI: 0.0006–0.94; p = 0.04). Conclusions. Significant differences in sagittal knee joint morphology parameters in osteoarthritis were demonstrated depending on the mJLO.*

*Мета. Оцінити рентгенологічні особливості сагітальної морфології колінних суглобів за остеоартриту з урахуванням нахилу суглобової лінії, визначеного за авторською методикою (mJLO). Методи. Проаналізовано 62 рентгенограми колінних суглобів, виконані в боковій проєкції, 45 хворих із медіальним гонартрозом. Серед рентгенографічних критеріїв, вивчали: задній дистальний кут стегнової кістки (PDFA); індекс заднього виросткового зсуву (PCOR); задній нахил плато великогомілкової кістки (PTS); горбистісно-модифікований тібіальний нахил (TMTS); кут інфлексії горбистості великогомілкової кістки (TTIA). Розраховували mJLO за формулою: aMPTA + aLDFA + 6°. Значення mJLO < 177° визначали як дистальний нахил лінії суглоба (AD), mJLO 177°–183° — як нейтральний (AN), mJLO > 183° — як проксимальний (AP). Значущими вважали відмінності за p ≤ 0,05. Результати. Встановлено AD у 43 (69,35 %) хворих, AN — у 16 (25,81 %), AP — у 3 (4,84 %). Зростання mJLO асоційовано зі зменшенням PDFA (τ = –0,25, p = 0,004) та PCOR (τ = –0,22, p = 0,01). Вищі шанси AD встановлено за PDFA > 88° (OR = 3,63; CI: 1,20–12,33; p = 0,02), PTS > 8° (OR = 5,22; CI: 1,65–19,40; p = 0,004). Нижчу ймовірність AD доведено за показників PDFA < 78° (OR = 0,08; CI: 0,01–0,34; p = 0,0005), PTS 3°–8° (OR = 0,25; CI: 0,07–0,76; p = 0,01). У обстежених зі значеннями PTS > 8° доведено нижчий ризик AN (OR = 0,28; CI: 0,07–0,90; p = 0,03). Вищі шанси AP встановлено за PDFA < 78° (OR = 49,00; CI: 4,17–6846,81; p = 0,001), PCOR < 0,44 (OR = 11,67; CI: 1,06–1596,60; p = 0,04), тоді як наявність PCOR > 0,44 знижує ймовірність вказаного типу нахилу (OR = 0,09; CI: 0,0006–0,94; p = 0,04). Висновки. Доведено значущу відмінність досліджуваних параметрів сагітальної морфології колінних суглобів за остеоартриту залежно від mJLO. Ключові слова. Остеоартрит, колінний суглоб, персоналізація, дегенеративно-дистрофічні захворювання суглобів, морфологія.*

**Keywords.** Osteoarthritis, knee joint, personalization, degenerative joint diseases, morphology

## Introduction

Osteoarthritis (OA) is a chronic, progressive degenerative joint disease characterized by a spectrum of pathological changes, including degeneration of the articular cartilage, remodeling of the subchondral bone, formation of osteophytes, development of synovitis, and involvement of periarticular structures [1, 2].

Knee OA accounts for about 85 % of the total burden of degenerative joint diseases [3]. More than 250 million people worldwide suffer from knee OA, and according to Y. Lv et al., the number of patients is estimated at 374.7 million [1, 4, 5]. In recent years, a clear upward trend in the prevalence of OA has been observed, which is associated with global population aging and a rising frequency of comorbid conditions [2]. Epidemiological data indicate that between 2005 and 2015, the prevalence of knee OA increased by 32.7 %, and between 1992 and 2021 — by 124.51 % [4, 5].

The knee joint is characterized by complex anatomy and pronounced interindividual morphological variability [6]. In the surgical treatment of knee OA, the concept of kinematic alignment in total knee arthroplasty, which aims to reproduce the natural alignment of the lower limb axis, is gaining popularity. Its application allows restoration of the native spatial relationships and reduction of tissue trauma compared with mechanical alignment [7]. However, most studies on personalized knee arthroplasty have focused on evaluating structural changes in the coronal plane, while sagittal parameters have been investigated in less detail.

One of the most studied sagittal morphological parameters is the posterior tibial slope (PTS). It is known that PTS serves as an informative indicator for evaluating the condition of the tibial articular surface. High interindividual variability of this parameter depending on sex, ethnicity, measurement technique, and disease course has been confirmed by several studies [7–9]. Differences between medial (MPTS) and lateral (LPTS) PTS values within the same joint have also been established [6, 8, 9]. For instance, in a study by M. Meier et al., analysis of Computed Tomography scans from 234 patients with knee OA demonstrated variability in MPTS values ranging from –4.3° to 16.8°, and LPTS from –2.9° to 17.2°, with a mean intraindividual difference of 2.6° ± 2.0° (up to 9.5°) [8]. The difference between MPTS 8.4° ± 4.0° and LPTS 9.2° ± 3.6° in patients with knee OA was also confirmed by A. Siddiqi et al. Moreover, their study demonstrated that, compared with healthy individuals, patients with knee OA had lower MPTS values (8.4° ± 4.0° vs. 9.2° ± 4.0°) and higher LPTS values (9.2° ± 3.6° vs. 7.2° ± 3.3°), highlighting the need for a personalized approach to arthroplasty [9].

An important component of knee joint morphology assessment is the joint line obliquity (JLO). In the Coronal Plane Alignment of the Knee (CPAK) system, developed by S. J. MacDessi et al., JLO is one of the two key parameters for joint phenotyping, calculated as the sum of the mechanical lateral distal femoral angle (LDFA) and the mechanical medial proximal tibial angle (MPTA) [10]. In addition, JLO is also defined as a radiographic angle formed between the line tangent to the tibial plateau and a horizontal line parallel to the ground. The radiographic JLO angle makes it possible to characterize the functional inclination of the joint plane under axial loading of the lower limb [11]. In the context of personalized orthopedics, JLO is considered one of the key factors influencing the restoration of optimal axial balance of the lower limb.

Despite significant progress in the study of coronal parameters of the knee joint, the variability of its sagittal morphology in OA, taking into account the JLO, remains insufficiently investigated, highlighting the need for further research.

The null hypothesis of the study is that there are no differences in the sagittal morphology parameters of the knee joints in medial OA when accounting for the JLO.

*Objective:* to evaluate the radiographic features of sagittal knee joint morphology in medial osteoarthritis, taking into account the joint line obliquity as determined by the authors' original method joint line obliquity.

## Material and Methods

In the present observational cross-sectional study, the results of radiographic examinations of 62 knee joints affected by medial OA in 45 patients who underwent inpatient treatment at the Traumatology Department of the Vinnytsia City Clinical Emergency Hospital during the period 2017–2025 were analyzed. The mean age of patients was (63.84 ± 8.21) years (n = 45), with a mean age of (63.40 ± 8.79) years (n = 62) across the groups. The study group included 17 (37.78 %) men and 28 (62.22 %) women. Unilateral knee OA was recorded in 28 (62.22 %) patients, whereas bilateral involvement was observed in 17 (37.78 %).

Inclusion criteria: primary medial knee OA stage II–III according to the Kellgren-Lawrence classification; secondary medial knee OA, including cases following spontaneous osteonecrosis of the medial femoral condyle; satisfactory condition of the lateral compartment of the knee joint (intact meniscus and full-thickness articular cartilage); integrity of the knee ligamentous structures; ability to achieve full extension of the knee joint or presence of flexion contracture < 10°.

Exclusion criteria: bicompartmental knee OA (Kellgren–Lawrence grades I–IV); secondary post-traumatic OA after tibial plateau fracture; previous surgical interventions in the proximal tibia (except arthroscopic meniscectomy); presence of flexion contracture > 10°; instability of the knee ligaments; secondary OA associated with dysplastic bone changes, metabolic disorders, or other diseases (ochronosis, Gaucher's disease, Paget's disease, osteopetrosis); active or latent infection.

For the analysis, lateral radiographs of the knee joints obtained at 30° of flexion were used. In contrast, standard (short) anteroposterior radiographs of the knee joints under weight-bearing conditions were used to assess the mJLO.

Among the radiographic criteria assessed in the sagittal plane were:

– *Posterior Distal Femoral Angle (PDFA)* — the angle formed between the anatomical axis of the femur and the distal femoral joint orientation line. Reference values for the PDFA were considered to be in the range of 79°–87° [12].

– *Posterior Condylar Offset Ratio (PCOR)* — calculated as the ratio of the distance between two vertical lines, one drawn along the posterior cortical surface of the femur and the other passing through the most prominent point of the posterior condylar surface, to the distance measured from the anterior cortical surface of the femur to the most prominent point of the posterior condylar surface. The reference value of the index was defined as 0.44.

– *Posterior Tibial Slope (PTS)* — the angle between a line tangential to the proximal tibial joint surface and a line perpendicular to the anatomical axis of the tibial shaft. Reference values for PTS were considered within the range of 3°–8° [13].

In addition to the commonly accepted parameters, sagittal morphometric indices of the proximal tibia specifically developed for this study were evaluated:

– *Tuberosity-Modified Tibial Slope (TMTS)* — the angle between a horizontal line drawn along the proximal articular surface of the tibia and an oblique line passing through the most prominent points of the tibial tuberosity and the posterior margin of the tibial plateau.

– *Tibial Tuberosity Inflection Angle (TTIA)* — the angle formed between two lines drawn along the anterior cortical surface of the tibia in proximal and distal directions, intersecting at the most prominent point of the tibial tuberosity.

The present study utilized a common clinical database with our previous publication [13]; however, the subjects of analysis and the approach to patient grouping differed. Morphological assessment was performed using distinct original methods developed by the authors to provide a comprehensive investigation of the pathology.

The assessment of knee JLO was performed according to the authors' method, developed based on the principles of the CPAK system as a prototype. The modified JLO (mJLO) was calculated using the formula: mJLO = aMPTA + aLDFA + 6°, where 6° was considered a correction factor reflecting the valgus deviation of the anatomical axis relative to the mechanical axis [14]. The obtained values were interpreted according to the recommendations of the original method. An mJLO value of < 177° was defined as apex distal (AD); values within 177°–183° were considered apex neutral (AN); and values > 183° were defined as apex proximal (AP) [10]. For internal validation, assessment of measurement repeatability, and evaluation of the stability of patient distribution among the AD, AN, and AP groups when using the mJLO, a sensitivity analysis of the model was performed. In this analysis, the correction coefficient was varied by ± 1° (without shifting the threshold boundaries for AD, AN, and AP), followed by recalculation of the mJLO and subsequent comparison between the groups. A high degree of correlation between morphological knee parameters measured on standard anteroposterior radiographs and those obtained from full-length radiographs was demonstrated in the study by M. Unal et al. [15], which provided the rationale for adopting the CPAK model as a prototype.

The primary hypothesis was to determine differences in sagittal knee morphology in medial osteoarthritis depending on the mJLO. Secondary parameters, such as PDFA, PCOR, PTS, TMTS, and TTIA, were analyzed separately as secondary measures without adjustment for multiple comparisons, since the study was not designed to assess a cumulative effect or hierarchy of parameters.

The relationship between the investigated sagittal morphology parameters and the femorotibial angle (FTA) was also considered. The FTA was determined in the coronal plane as the angle between the anatomical axes of the femur and the tibia [14]. Additionally, the prognostic value of the defined parameters for the identification of the knee JLO in OA was analyzed.

Morphometric measurements were performed by two independent observers. To assess interobserver agreement, the intraclass correlation coefficient (ICC) was calculated using a two-way mixed-effects model with absolute agreement. The established ICC values were > 0.85, indicating the reliability of the obtained measurement results.

The study was conducted in accordance with the ethical principles of the World Medical Association (WMA) Declaration of Helsinki– Ethical Principles for Medical Research Involving Human Subjects (Seventh Revision, adopted at the 64th WMA General Assembly) [16], the Council of Europe Convention on Human Rights and Biomedicine [17], as well as current national ethical standards [18] and approved by the bioethics committee of the Medical Center «Angels Clinic», Vinnytsia (protocol No. 7 dated 19.09.2025). All participants were informed about their involvement in the study, and written informed consent was obtained. Personal data of the examined patients were anonymized to ensure confidentiality.

Statistical analysis of numerical data was performed using StatSoft STATISTICA 13 and the RStudio environment. For evaluation and analysis of quantitative data, descriptive statistical methods were applied. Quantitative variables were presented as mean ± standard deviation (M ± SD), and categorical variables were expressed as absolute numbers (n) and corresponding percentages (%). For comparison between independent groups, the nonparametric Kruskal–Wallis test was used, and associations between variables were assessed using Kendall's rank correlation coefficient (τ). The prognostic value of sagittal morphology parameters in determining joint line obliquity was evaluated using a binary logistic regression model, calculating odds ratios (OR) with 95 % confidence intervals (CI). To minimize potential estimation bias associated with group imbalance and the presence of rare events in the model, Firth's penalized likelihood estimation method was applied. Statistical significance was set at $p \leq 0.05$.

## Results

When evaluating the mJLO value, in the majority of examined patients, AD was identified in 43 (69.35 %), AN in 16 (25.81 %), and AP in 3 (4.84 %). The mean mJLO in the study group was 174.89° ± 5.41°. The average mJLO in individuals with AD was 172.40° ± 4.05°, in patients with AN — 179.25° ± 1.81° and 187.33° ± 2.52° in patients with AP; the difference was statistically significant ($p < 0.00001$). With variation of the correction coefficient by ± 1°, the distribution of patients among the AD, AN, and AP groups remained nearly unchanged and statistically nonsignificant, confirming the stability of applying the mJLO formula to short radiographic images.

Analyzing the position of the anatomical axis of the lower limb, it was found that the mean FTA angle in patients with AD was 175.88° ± 4.72°, corresponding to a varus deviation of the lower limb axis; in individuals with AN — a neutral position of the axis (179.97° ± 6.68°); and the highest values, corresponding to valgus deviation of the lower limb axis, were observed in individuals with AP — 185.00° ± 3.00°. The difference was statistically significant ($p = 0.009$). The mean FTA angle in patients of the study group was 177.38° ± 5.73°. A weak positive correlation was found between the FTA angle and mJLO values ($\tau = +0.22$, $p = 0.01$), indicating higher FTA values and, accordingly, a valgus position of the lower limb axis in patients with a more proximal position of the joint line.

When evaluating the morphological parameters of the distal femur, the highest PDFA values were found in the group of patients with AD, the lowest in those with AP, while patients with AN demonstrated intermediate values. The difference was statistically significant ($p = 0.004$) (table 1). In addition, a weak negative correlation was established between the PDFA and mJLO values ($\tau = -0.25$, $p = 0.004$), indicating significantly lower angle values in patients with a more proximal orientation of the joint line. The mean PDFA in patients of the study group was 84.98° ± 5.62°.

PDFA values < 78° were recorded in 10 (16.13 %) patients, including all individuals with AP, 31.25 % with AN, and 4.65 % with AD. The difference was statistically significant ($p < 0.00001$). PDFA values of 79°–87° were observed in 22 (35.48 %) patients, including 37.21 % of those with AD and 37.50 % with AN. In AP patients, values of the angle corresponding to the reference range were not observed; the difference was not statistically significant ($p = 0.43$). PDFA values > 88° were found in the majority of patients — 30 (48.39 %). Increased PDFA values were observed in the vast majority of AD patients (figure 1) and in 31.25 % of those with AN, while in patients with AP such values were not recorded; the difference was statistically significant ($p = 0.04$).

When analyzing the PCOR values, the highest indices were recorded in patients with AD, whereas the lowest were observed in those with AP; patients with AN demonstrated intermediate values. The difference was statistically significant ($p = 0.03$). The mean PCOR in the cohort was 0.44 ± 0.08. Significantly higher PCOR values were associated with lower mJLO values and, consequently, a more distal orientation of the knee joint line ($\tau = -0.22$, $p = 0.01$).

A PCOR value of < 0.44 was established in 25 (40.32 %) patients of the group, including all patients with AP, 50.00 % of those with AN, and 32.56 % of the examined individuals with AD; the difference in frequency indices was statistically significant ($p = 0.048$). It should be noted that a PCOR ratio of 0.44, which is defined as the reference value, was not observed in any case. In the majority of patients — 37 (59.68 %) PCOR values > 0.44 were recorded. These were identified in most of the examined individuals with AD, as well as in 50.00 % of patients with AN, while such values were not observed in patients with AP; the difference was statistically significant ($p = 0.048$).

When analyzing the morphological parameters of the proximal tibia in the sagittal plane, the mean PTS angle was found to be 9.00° ± 4.18°. The highest values of this angle were detected in patients with AD, whereas in individuals with AN and AP the mean PTS values corresponded to the reference range (table 2). Comparison of PTS angle values between groups formed according to the position of the knee joint orientation line demonstrated a statistically significant difference ($p = 0.04$). However, no reliable correlation was found between the PTS angle values and the mJLO ($\tau = -0.15$, $p = 0.09$).

A PTS value of < 3° was identified in 1 (1.61 %) patient of the group, who had AN; such values were not observed in the groups of patients with AD or AP, and the difference in frequencies was not statistically significant ($p = 0.24$). PTS values within the range of 3°–8° were found in 31 (50.00 %) patients of the group. In particular, angle values corresponding to the reference range were observed in all examined individuals with AP (Figure 2), the vast majority of patients with AN, and in 39.53 % of those with AD; the difference was statistically significant ($p = 0.03$). PTS values > 8° were recorded in 30 (48.39 %) individuals of the group. Elevated angle values were observed in the majority of patients with AD, as well as in 25.00 % of those with AN, while such values were not registered in the AP group; the difference was statistically significant ($p = 0.01$).

The mean TMTS angle was 36.48° ± 6.28°. The highest values of this angle were detected in patients with AP, the lowest in those with AD, while intermediate values were recorded in the AN group (Figure 3). Comparison of TMTS angle values among

*Table 1*

**Characteristics of the morphological parameters of the distal femur**

| Parameter | mJLO | | | p |
|---|---|---|---|---|
| | AD (n = 43) | AN (n = 16) | AP (n = 3) | |
| PDFA | 86.53° ± 4.21° | 83.00° ± 6.37° | 73.33° ± 1.53° | 0.004* |
| < 78° | 2 (4.65 %) | 5 (31.25 %) | 3 (100.00 %) | < 0.00001* |
| 79°–87° | 16 (37.21 %) | 6 (37.50 %) | 0 | 0.430 |
| > 88° | 25 (58.14 %) | 5 (31.25 %) | 0 | 0.040* |
| PCOR | 0.45 ± 0.07 | 0.42 ± 0.11 | 0.34 ± 0.02 | 0.030* |
| < 0.44 | 14 (32.56 %) | 8 (50.00 %) | 3 (100.00 %) | 0.048* |
| 0.44 | 0 | 0 | 0 | 1.000 |
| > 0.44 | 29 (67.44 %) | 8 (50.00 %) | 0 | 0.048* |

*Note:* * — A statistically significant difference was observed at $p \leq 0.05$.

*Table 2*

**Characteristics of the morphological parameters of the proximal tibia**

| Parameter | mJLO | | | p |
|---|---|---|---|---|
| | AD (n = 72) | AN (n = 25) | AP (n = 3) | |
| PTS | 9.67 ± 3.87 | 7.81 ± 4.89 | 5.67 ± 1.53 | 0.04* |
| < 3° | 0 | 1 (6.25 %) | 0 | 0.24 |
| 3°–8° | 17 (39.53 %) | 11 (68.75 %) | 3 (100.00 %) | 0.03* |
| > 8° | 26 (60.47 %) | 4 (25.00 %) | 0 | 0.01* |
| TMTS | 35.41 ± 4.98 | 37.13 ± 7.66 | 48.33 ± 1.53 | 0.02* |
| TTIA | 159.64° ± 7.32° | 161.63° ± 4.81° | 167.67° ± 3.51° | 0.08 |

*Note:* * — A statistically significant difference was observed at $p \leq 0.05$.

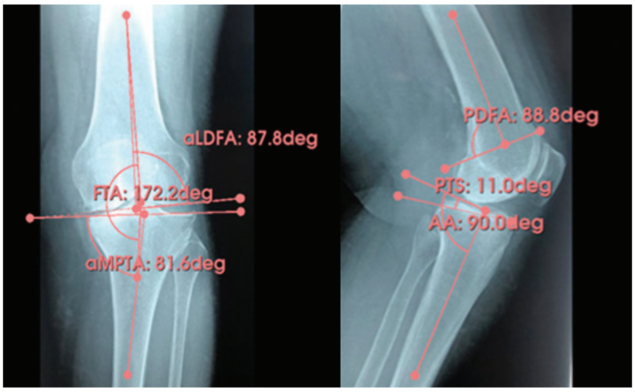


**Fig. 1.** Anteroposterior and lateral X-ray demonstrating medial compartment osteoarthritis of the left knee, grade 3. mJLO = 87.8° + 81.6° + 6° = 175.4°, indicating AD. FTA = 172.2°; PDFA = 88.8°; PTS = 11.0°; AA (additional angle) = 90°

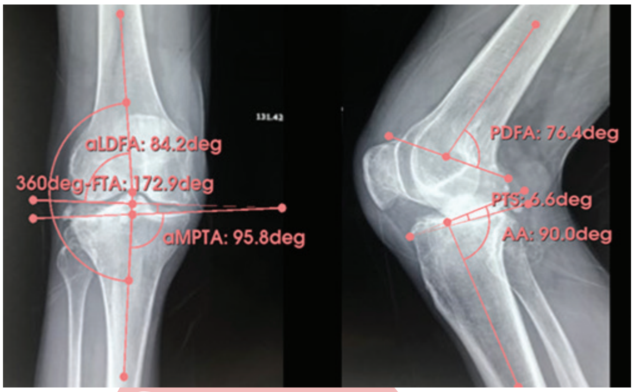


**Fig. 2.** Anteroposterior and lateral X-rays demonstrating medial compartment osteoarthritis of the right knee, grade 3. mJLO = 84.2° + 95.8° + 6° = 186.0°, indicating AP. FTA = 187.1°; PDFA = 76.4°; PTS = 6.6°; AA (additional angle) = 90°

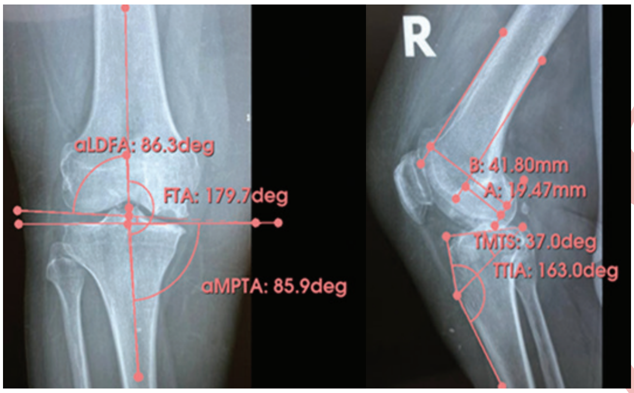


**Fig. 3.** Anteroposterior and lateral X-ray demonstrating medial compartment osteoarthritis of the right knee medial osteoarthritis of the right knee, grade 2. mJLO = 86.3° + 85.9° + 6° = 178.2°, indicating AN. FTA = 179.7°; PCOR = A : B = 19.47 : 41.80 = 0.47; TMTS = 37.0°; TTIA = 163.0°

groups formed according to the position of the joint orientation line demonstrated a statistically significant difference (p = 0.02). No significant correlation was found between the TMTS angle values and the mJLO (τ = +0.13, p = 0.13).

Evaluating TTIA values, the mean angle was 160.54° ± 6.81°. The highest mean values of this angle were recorded in patients with AP, the lowest in individuals with AD, while intermediate values were found in those with AN. The differences in TTIA angle values among the groups were not statistically significant (p = 0.08). No significant correlation was established between TTIA values and the mJLO (τ = +0.12, p = 0.16).

Assessing the prognostic value of sagittal morphology parameters of the distal femur in determining mJLO variant, we found significantly higher odds of AD in patients with PDFA > 88° (OR = 3.63; CI: 1.20–12.33; p = 0.02) (table 3). Conversely, individuals with PDFA < 78° demonstrated a lower likelihood of AD (OR = 0.08; CI: 0.01–0.34; p = 0.0005) and higher odds of AP (OR = 49.00; CI: 4.17–6846.81; p = 0.001).

It is noteworthy that PCOR < 0.44 was associated with higher odds of AP (OR = 11.67; CI: 1.06–1596.60; p = 0.04), whereas individuals with PCOR > 0.44 demonstrated a lower likelihood of this obliquity type (OR = 0.09; CI: 0.0006–0.94; p = 0.04).

The presence of PTS angle values within the reference range was associated with significantly lower odds of AD (OR = 0.25; CI: 0.07–0.76; p = 0.01). In patients with PTS values > 8°, significantly higher odds of AD were observed (OR = 5.22; CI: 1.65–19.40; p = 0.004) and a lower risk of AN (OR = 0.28; CI: 0.07–0.90; p = 0.03).

## Discussion

The obtained results indicate a high variability of the sagittal morphology parameters of the knee joints in OA, depending on the orientation of the joint line. According to the author's method of mJLO assessment, AD was recorded in the majority of examined cases — 69.35 %, AN — in 25.81 %, and AP — in 4.84 %. The stability of intergroup differences in mJLO was preserved when the correction coefficient of + 6° was varied within ± 1°, indicating high robustness of the calculated parameters, internal consistency of the method, and the correctness of the applied formula, even under conditions of minor measurement error and without direct validation on full-length radiographs. A substantial predominance of AD of the knee joint, calculated using the CPAK method, in OA has been confirmed by the results of numerous studies [19–22].

In particular, according to the findings of the original multicenter study by S. J. MacDessi et al., which analyzed orthoradiographs of 500 patients from European and Australian populations with knee OA, AD was identified in 67 %, AN — in 31.8 %, and AP — in 2.6 % [10].

*Table 3*

**Predictive value of the morphological parameters of the distal femur**

| Parameter | mJLO | | |
|---|---|---|---|
| | AD | AN | AP |
| PDFA | | | |
| < 78° | OR = 0.08<br>CI (0.01–0.34)<br>p = 0.0005 | OR = 3.61<br>CI (0.92–14.40)<br>p = 0.07 | OR = 49.00<br>CI (4.17–6846.81)<br>p = 0.001 |
| 79°–87° | OR = 1.25<br>CI (0.42–3.99)<br>p = 0.70 | OR = 1.14<br>CI (0.35–3.57) p = 0.82 | OR = 0.24<br>CI (0.002–2.62)<br>p = 0.28 |
| > 88° | OR = 3.63<br>CI (1.20–12.33)<br>p = 0,02 | OR = 0.40<br>CI (0.12–1.25)<br>p = 0.12 | OR = 0.14<br>CI (0.001–1.52)<br>p = 0.15 |
| PCOR | | | |
| < 0.44 | OR = 0,36<br>CI (0,12–1,06)<br>p = 0,06 | OR = 1.69<br>CI (0.55–5.25)<br>p = 0.36 | OR = 11.67<br>CI (1.06–1596.60)<br>p = 0.04 |
| > 0.44 | OR = 2,75<br>CI (0,94–8,41)<br>p = 0,06 | OR = 0.59<br>CI (0.19–1.83)<br>p = 0.36 | OR = 0.09<br>CI (0.0006–0.94)<br>p = 0.04 |

*Note:* * — CI not available.

*Table 4*

**Predictive value of the morphological parameters of the proximal tibia**

| Parameter | mJLO | | |
|---|---|---|---|
| | AD | AN | AP |
| PTS | | | |
| < 3° | OR = 0.14<br>CI (0.001–2.78)<br>p = 0.20 | OR = 9.00<br>CI (0.46–1341.77)<br>p = 0.15 | OR = 5.57<br>CI (0.04–128.15)<br>p = 0.38 |
| 3°–8° | OR = 0.25<br>CI (0.07–0.76)<br>p = 0.01 | OR = 2.70<br>CI (0.87–9.29)<br>p = 0.09 | OR = 7.74<br>CI (0.71–1057.63)<br>p = 0.10 |
| > 8° | OR = 5.22<br>CI (1.65–19.40)<br>p = 0.004 | OR = 0.28<br>CI (0.07– 0.90)<br>p = 0.03 | OR = 0.14<br>CI (0.001–1.52)<br>p = 0.11 |

*Note:* * — CI not available.

A similar distribution was reported by S. Agarwal et al., who presented the results of a retrospective analysis of orthoradiographic data of 134 patients (33 men, 101 women; mean age — 70 years) with knee OA. In accordance with the CPAK method, the researchers recorded AD in 66.41 %, AN — in 32.08 %, and AP — in 1.48 % [23].

In a retrospective study by S. E. Kim et al., data from 164 patients with knee OA predominantly affecting the medial compartment were analyzed. The authors established that the mean JLO, according to the CPAK method, was 175.8° ± 2.9° (range: 167.4°–185.7°). AD was observed in 67.1 %, AN — in 32.4 %, and AP — in 0.6 % [24].

When analyzing the morphological parameters of the distal femur determined in the sagittal plane, we established an increase in PDFA values in patients with AD, which was primarily due to the downward displacement of the horizontal axis drawn through the femoral condyles. In patients with AP, a decrease in PDFA values was observed as a result of the upward displacement of the axis passing through the condyles. In patients with degenerative-dystrophic diseases of the knee joint and AN, no general trend of displacement of the horizontal axis through the condyles was identified; in the majority of examined individuals — 37.50 %, the PDFA values corresponded to the reference range. A weak inverse correlation between PDFA and mJLO was established, confirming that a more proximal position of the joint line is associated with lower PDFA values. In addition, it was demonstrated that PDFA > 88° was associated with significantly higher odds of developing AD, whereas PDFA < 78° reduced the likelihood of this obliquity type and was linked to higher odds of AP.

When analyzing PCOR values, the highest indicators were observed in the AD group, whereas the lowest values were recorded in individuals with AP. A weak inverse correlation with mJLO indicated a tendency for PCOR to decrease with a more proximal obliquity of the joint line. In the majority of patients with AD (67.44 %) and in every second patient with AN, PCOR values > 0.44 were identified, which indicated a higher risk of anterior cruciate ligament injury in these groups. In all patients with AP and in half of the individuals with AN, PCOR values < 0.44 were recorded, which are associated with limitations of knee flexion. Notably, PCOR < 0.44 was associated with a higher likelihood of AP, whereas PCOR > 0.44 reduced the odds of developing this obliquity type.

With regard to the proximal tibia, the highest PTS values were recorded in individuals with AD, whereas the lowest values were observed in those with AP. Although the correlation with mJLO was statistically insignificant, the analysis of prognostic value demonstrated that PTS in the range of 3°–8° decreases the probability of AD. The presence of PTS > 8° was associated with a higher risk of AD and a lower likelihood of AN.

Comparable mean PTS values (8.6°–9.1°) were reported by L. Xin et al. in a cohort study of patients with knee OA [25], whereas in the work of S. K. Saidapur et al., this parameter was higher — 11.5° ± 1.34° in patients with early knee OA in the Indian population [26]. The high interethnic variability of PTS values has been confirmed by numerous population-based studies. The mean angle was reported as 9.90° in Americans, 13.30° in Chinese, 4°–7° in Germans, 11° in Japanese, 5.8°–6.6° in the Saudi Arabian population, and 7° in the East African population [27, 28].

Other parameters of sagittal morphology, in particular TMTS and TTIA, demonstrated more selective associations with mJLO.

Summarizing our findings, in patients with AD the leading morphological factors of changes in knee OA are the downward deviation of the axis drawn through the femoral condyles and the associated increase in PDFA and PCOR values, as well as the downward displacement of the axis drawn through the tibial condyles, which results in a decrease in TMTS values and an increase in PTS values. All these transformations indicate a higher risk of anterior cruciate ligament injury in patients with AD. In addition, the anterior displacement of the tibial diaphyseal axis in patients with AD, confirmed by low TTIA values, creates conditions that may lead to excessive tension of the anterior cruciate ligament and its injury.

The importance of PTS as a risk factor for anterior cruciate ligament injury has been confirmed by the findings of Y. Hiranaka et al., who identified an association between higher PTS values and anterior tibial translation [29], as well as by the biomechanical investigations of R. S. Dean et al., which demonstrated a linear increase in tensile stress on the ligament with increasing PTS [30]. In the study by B. Springer et al., it was shown that in OA with varus deformity, the combination of varus ≥ 10° and tibiofemoral subluxation ≥ 6 mm indicates a high probability of functional insufficiency of the ACL [31].

In patients with AP, alterations were observed due to the upward displacement of the axis passing through the femoral condyles, which corresponded to reduced PDFA and PCOR values, as well as increased TMTS angles and decreased PTS angles, resulting from the upward deviation of the axis passing through the tibial condyles. The morphological characteristics of the knee joint in patients with AP indicate a distinct load-bearing axis and potentially a different mechanism of degenerative changes. AP is characterized by higher TTIA values and a corresponding posterior displacement of the diaphyseal axis, which is associated with a lower risk of anterior cruciate ligament overstrain and increased tension of the posterior cruciate ligament.

In individuals with AN, intermediate values of the investigated angles were identified in most cases.

The identified mJLO knee variants may potentially influence the choice of surgical strategy in the treatment of knee osteoarthritis. However, the issue of adapting preoperative planning to a specific morphotype remains a subject of further research and currently lacks sufficient evidence.

The *limitations* of the present study, reflecting actual clinical practice, are the potential variability in the acquisition of radiographs across different medical institutions and the uneven distribution of subjects among groups. Despite the single-center nature of the study, radiographs may have been obtained from different medical facilities before inclusion, potentially affecting baseline data standardization. We were unable to control the technical parameters of external radiographs (beam angle, object distance, patient positioning, equipment type and calibration, image processing settings). Excluding external radiographs was not possible. To minimize the impact of these factors, the analysis focused on angular morphometric parameters, which are less sensitive to projection errors. In the present study, reproducibility of the morphometric measurements was evaluated overall; separate ICC analysis for the newly introduced parameters TMTS and TTIA was not performed. Establishing threshold values and clinical interpretation for these measures requires a dedicated investigation, which is planned for future research. Moreover, the partial overlap of clinical material with our previous studies may limit the generalizability of the results; however, the use of distinct methodological approaches ensured the independence of the obtained results and conclusions. Despite these limitations, the results of the comprehensive morphometric analysis enabled the identification of key morphological markers of degenerative changes in relation to the mJLO.

The results of this study demonstrated differences in the sagittal morphological characteristics of the distal femur and the proximal tibia according to the mJLO variant, thereby allowing *rejection of the null hypothesis.*

## Conclusions

A significant difference in the sagittal morphological parameters of the distal femur and the proximal tibia was demonstrated in patients with medial knee osteoarthritis depending on the joint line obliquity, as determined using the authors' method (mJLO).

The apex distal, apex neutral, and apex proximal mJLO variants demonstrated specific and reproducible morphological patterns, indicating that sagittal joint geometry is systematically related to the direction of joint line obliquity.

A comprehensive assessment of morphological parameters may assist in predicting the mJLO variant during preoperative planning; however, further studies are required to clarify these associations, particularly for the less frequent variants.

**Conflict of interest.** The authors declare no conflict of interest.

**Prospects for further research.** In future studies, it is advisable to consider the combined use of frontal plane parameters and lateral angles, which would allow for a more comprehensive assessment of knee joint morphology. This approach may facilitate personalized planning of alignment in arthroplasty and osteotomies, minimizing the risk of postoperative imbalance and excessive JLO.

**Funding information.** The presented study is non-commercial and received no external financial support from any institutions, organizations, or foundations.

**Authors' contributions.** Kostrub O. O. — final approval of the article; Blonskyi R. I. — determination of the direction and concept of the study, analysis of the obtained results; Kylymniuk L. O. — collection of clinical data and results of patients' radiographic examinations, writing of the main text; Khytruk K. M. — conducting a literature search, statistical analysis of the results; Khytruk S. V. — participation in writing the introduction and discussion of results, preparation of the reference list.

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| 25.09.2025 | 12.11.2025 | 14.11.2025 |


# ОСОБЛИВОСТІ РЕНТГЕНОЛОГІЧНОЇ ДІАГНОСТИКИ ОСТЕОАРТРИТУ КОЛІННОГО СУГЛОБА В БОКОВІЙ ПРОЄКЦІЇ ЗАЛЕЖНО ВІД НАХИЛУ СУГЛОБОВОЇ ЛІНІЇ


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