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Morphological parameters of patellar position depending on the joint line obliquity in knee osteoarthritis

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Aim. To analyze the differences in the morphological parameters of patellar position depending on the joint line obliquity, as determined using the authors' proprietary method, in patients with medial knee osteoarthritis.

Materials and methods. Radiographic indices of patellar position were analyzed in 45 patients with medial knee osteoarthritis (n = 62 knees). The mean age of the patients was 63.84 ± 8.21 years. The following radiographic indices were calculated: Insall–Salvati, Caton–Deschamps, Grelsamer–Meadows, and Blackburne–Peel. Lateral knee radiographs were obtained with the joint flexed at 30°. The modified joint line obliquity (mJLO) angle was assessed according to the authors' original method. An mJLO value of <177° was classified as apex distal (AD), 177–183° as apex neutral (AN), and >183° as apex proximal (AP). Statistical analysis was performed using Statistica 13 and RStudio software. The level of statistical significance was set at $p \leq 0.05$.

Results. AD was identified in 43 (69.35 %) cases, AN in 16 (25.81 %), and AP in 3 (4.84 %). The mean mJLO value was 172.40 ± 4.05° in the AD group, 179.25 ± 1.81° in the AN group, and 187.33 ± 2.52° in the AP group ($p < 0.00001$). Significant differences were found among the groups in the mean values of the Insall–Salvati ($p = 0.04$), Caton–Deschamps ($p = 0.01$), and Blackburne–Peel ($p = 0.01$) indices. Signs of patella alta were more frequently observed in the AP group, whereas normal or low patellar positions predominated in the AD and AN groups. A higher patellar position was demonstrated in patients with a more proximal joint line inclination, confirmed by significant correlations: Insall–Salvati ratio ($\tau = +0.24$, $p = 0.006$), Caton–Deschamps index ($\tau = +0.18$, $p = 0.04$), Grelsamer–Meadows index ($\tau = +0.23$, $p = 0.009$), and Blackburne–Peel ratio ($\tau = +0.27$, $p = 0.002$). Predictive indicators of AD included: Insall–Salvati ratio 0.8–1.2 (OR = 4.39, CI (1.44–15.02), $p = 0.009$), Grelsamer–Meadows index <2 (OR = 4.39, CI (1.44–15.02), $p = 0.009$), and Blackburne–Peel ratio <0.8 (OR = 4.01, CI (1.31–12.89), $p = 0.02$). Probable predictors of AP were: Caton–Deschamps index >1.2 (OR = 833.00, CI (32.60–273970.85), $p = 0.000004$) and Blackburne–Peel ratio >1.0 (OR = 86.33, CI (6.90–12346.04), $p = 0.0003$).

Conclusions. Morphological parameters of patellar position are sensitive indicators of biomechanical alterations in medial knee osteoarthritis that depend on mJLO values. This supports their inclusion in a comprehensive radiometric program for personalized surgical planning.

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Морфологічні параметри положення надколінка залежно від нахилу суглобової лінії при остеоартриті колінного суглоба

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Мета роботи – проаналізувати відмінності морфологічних параметрів положення надколінка залежно від нахилу суглобової лінії, визначеного за авторською методикою (mJLO), у пацієнтів із медіальним остеоартритом колінного суглоба.

Матеріали і методи. Проаналізовано рентгенографічні індекси положення надколінка 45 пацієнтів із медіальним остеоартритом колінного суглоба (n = 62). Середній вік обстежених – 63,84 ± 8,21 року. Обчислили такі рентгенографічні індекси: Insall–Salvati, Caton–Deschamps, Grelsamer–Meadows та Blackburne–Peel. Проаналізували рентгенограми колінних суглобів, що виконані в боковій проєкції в положенні згинання коліна під кутом 30°. mJLO оцінювали відповідно до авторської методики. Значення mJLO <177° оцінювали як дистальний нахил суглобової лінії (AD), mJLO в діапазоні 177–183° – як нейтральний (AN), mJLO >183° – як проксимальний (AP). Для статистичного аналізу даних використано програми Statistica 13 та RStudio. Рівень статистичної значущості – $p \leq 0,05$.

Результати. AD встановлено у 43 (69,35 %) обстежених, AN – у 16 (25,81 %), AP – у 3 (4,84 %). Середнє значення mJLO в осіб з AD становило 172,40 ± 4,05°, з AN – 179,25 ± 1,81°, у пацієнтів з AP – 187,33 ± 2,52° ($p < 0,00001$). У сформованих групах встановлено значущі відмінності середніх індексів Insall–Salvati ($p = 0,04$), Caton–Deschamps ($p = 0,01$), Blackburne–Peel ($p = 0,01$). Ознаки patella alta частіше виявляли у

разі AP, натомість при AD та AN переважно фіксували ознаки нормального та низького стояння надколінка. Доведено вище положення надколінка у пацієнтів із більш проксимальним нахилом суглобової лінії, що підтверджено відповідними кореляційними зв'язками: Insall–Salvati ratio (τ = +0,24, p = 0,006), Caton–Deschamps index (τ = +0,18, p = 0,04), Grelsamer–Meadows index (τ = +0,23, p = 0,009), Blackburne–Peel (τ = +0,27, p = 0,002). Як прогностичні предиктори AD визначено Insall–Salvati ratio 0,8–1,2 (OR = 4,39 CI (1,44–15,02), p = 0,009), Grelsamer–Meadows index <2 (OR = 4,39, CI (1,44–15,02), p = 0,009), Blackburne–Peel ratio <0,8 (OR = 4,01, CI (1,31–12,89), p = 0,02). Імовірними факторами прогнозу AP є Caton–Deschamps index >1,2 (OR = 833,00, CI (32,60–273970,85), p = 0,000004), Blackburne–Peel ratio >1,0 (OR = 86,33, CI (6,90–12346,04), p = 0,0003).

Висновки. Морфологічні параметри положення надколінка – чутливі індикатори біомеханічних змін при медіальному остеоартриті колінного суглоба, що залежать від mJLO. Це підтверджує доцільність їх включення до комплексної рентгенометричної програми персоналізованого планування хірургічного втручання.

Сучасні медичні технології. 2026. Т. 18, № 1(68). С. 29-38

Knee osteoarthritis (OA) is one of the most common degenerative diseases of the musculoskeletal system, leading to persistent pain, progressive limitation of functional activity, and deterioration in patients' quality of life. The key factors in the pathogenesis of OA include degenerative changes in the articular cartilage, remodeling of the subchondral bone, osteophyte formation, and synovial inflammation; biomechanical and morphological factors also play an important role [1,2].

The knee joint is considered one of the most complex joints in the human body, exhibiting pronounced interindividual morphological variability [3]. An important component of the knee is the patella, whose position affects the distribution of contact loads and force vectors during movement. Abnormal patellar position is regarded as a risk factor for patellofemoral maltracking, joint instability, and the development and progression of knee degenerative changes [4,5].

In cases of patella alta, patellar contact with the femoral trochlea occurs at a greater degree of knee flexion, which is associated with an increased risk of recurrent subluxations and dislocations, anterior knee pain, and the development of secondary degenerative changes [4,6]. Conversely, patella baja or pseudo-patella baja is associated with pain, limited range of motion, and joint crepitus [4,7].

It should be noted that patella alta and patella baja are not merely isolated morphological phenomena but serve as significant risk factors for the development and progression of knee OA. In particular, their presence is associated with an uneven distribution of loads across joint structures and increased pressure on the lateral facet of the patella, leading to early degenerative changes. Moreover, alterations in patellar height are considered factors capable of modifying the course of gonarthrosis; therefore, assessment of patellar position is regarded as an important component in the diagnosis and prognosis of treatment outcomes in knee OA [8].

Numerous indices are used to determine patellar position, among which the most common are the Insall–Salvati, Blackburne–Peel, Caton–Deschamps, and Grelsamer–Meadows indices. However, their diagnostic potential is limited by the variability of anatomical landmarks and the absence of a universally accepted "gold standard" for measurement. Recent studies have shown that although each method has certain limitations, their combined use allows for greater reliability and reproducibility of results [7].

An equally important morphological factor that directly affects the interaction between the femoral trochlea and the patella is the joint line obliquity (JLO). JLO reflects the spatial orientation of the femoral and tibial condyles relative to the mechanical axis of the lower limb. It is well established that alterations in JLO lead to asymmetric loading of the knee joint structures, including the patellofemoral articulation, and influence the function of the extensor mechanism, particularly the position of the patella [9]. Excessive JLO is recognized as a biomechanical predictor of degenerative changes in the knee joint [10].

However, the relationship between JLO and patellar position in knee OA remains insufficiently understood. Despite the growing number of studies analyzing JLO or patellar position separately, data on the comprehensive assessment of these parameters in patients with knee OA are limited.

Therefore, investigating the associations between the morphological parameters of patellar position and JLO in OA represents a promising direction for gaining a deeper understanding of the anatomical and biomechanical characteristics of the knee joint, identifying risk factors for disease progression, and optimizing treatment strategies.

Aim

To analyze the differences in the morphological parameters of patellar position depending on the joint line obliquity, as determined using the authors' proprietary method, in patients with medial knee osteoarthritis.

Materials and methods

In this observational cross-sectional study, the results of radiographic examinations of 62 cases of knee OA with predominant involvement of the medial compartment were analyzed in 45 patients who underwent inpatient treatment at the Traumatology Department of Vinnytsia City Clinical Emergency Hospital between 2017 and 2025. The mean age of the examined patients was 63.84 ± 8.21 years (n = 45) (for the total sample – 63.40 ± 8.79 years, n = 62). The study group included 17 (37.78 %) men and 28 (62.22 %) women. Unilateral knee OA was observed in 28 (62.22 %) patients, while 17 (37.78 %) had bilateral disease.

The analysis was performed at the level of the joint without accounting for intraindividual correlation between knees of the

same patient. Both knees of a single individual were considered distinct structural variants and treated as independent observational units (n = 62).

Inclusion criteria: primary knee OA grade 2–3 according to the Kellgren–Lawrence classification with predominant involvement of the medial compartment; secondary knee OA with predominant medial compartment involvement, including cases following spontaneous osteonecrosis; satisfactory condition of the lateral compartment of the knee joint (intact meniscus and full-thickness articular cartilage); integrity of the knee ligamentous apparatus; ability to achieve full knee extension or presence of a flexion contracture of less than 10°.

Exclusion criteria: simultaneous degenerative involvement of both the medial and lateral compartments of the knee joint (grades 1–4); secondary post-traumatic OA following tibial plateau fracture; previous surgical interventions in the proximal tibia (except arthroscopic meniscectomy); presence of a flexion contracture greater than 10°; ligamentous instability of the knee joint; secondary OA associated with dysplastic bone changes, metabolic or other disorders (ochronosis, Gaucher's disease, Paget's disease, osteopetrosis); active or latent infection.

For the analysis, lateral knee radiographs obtained at 30° of knee flexion were used.

The characteristics of patellar position in knee OA were determined by calculating the radiographic indices of the Insall–Salvati, Caton–Deschamps, Grelsamer–Meadows, and Blackburne–Peel in groups formed according to the obliquity of the knee joint line, assessed using the authors' original method.

The Insall–Salvati index was defined as the ratio of the length of the patellar tendon to the maximum diagonal length of the patella. Patella baja was diagnosed when the index value was <0.8, patella norma when it was 0.8–1.2, and patella alta when it exceeded 1.2 [11].

The Caton–Deschamps index was defined as the ratio of the distance from the anterosuperior edge of the tibial plateau to the inferior margin of the patellar articular surface, divided by the length of the articular (posterior) surface of the patella. The results were interpreted as follows: patella baja <0.6; patella norma 0.6–1.2; patella alta >1.2 [12].

The Grelsamer–Meadows index, also known as the modified Insall–Salvati index, was calculated as the ratio between the distance from the inferior margin of the patellar articular surface to the most distal point of the patellar tendon attachment (tibial tuberosity) and the length of the patellar articular surface. A normal patellar position was defined as a Grelsamer–Meadows index <2, and patella alta as >2 [13].

The Blackburne–Peel index was calculated as the ratio between the distance from the inferior margin of the patellar articular surface to the extension of the tibial plateau line and the length of the patellar articular surface. Patella baja was defined when the index value was <0.8, patella norma at 0.8–1.0, and patella alta when >1.0 [14].

It should be noted that some of the clinical cases included in this study overlap with the database used in our previous work; however, the two studies differ in their scientific objectives, methodological approaches to group formation, and obtained results [15].

JLO was assessed according to the authors' proprietary method, developed based on the principles of the Coronal Plane Alignment of the Knee (CPAK) classification, which served as a prototype. The modified joint line obliquity (mJLO) was calculated using the formula: mJLO = aMPTA + aLDFA + 6°, where aMPTA was the anatomical medial proximal tibial angle, aLDFA was the anatomical lateral distal femoral angle, 6° was considered a correction coefficient representing the valgus deviation of the anatomical axis relative to the mechanical axis [16].

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 between 177–183° were defined as apex neutral (AN), and values >183° were defined as apex proximal (AP) [17]. The threshold intervals were adapted from the original CPAK system only for approximate categorization of mJLO, without implying equivalence to mechanical angle measurements.

To verify the robustness of the classification and assess the stability of the obtained results, a sensitivity analysis of the model was performed, in which the correction coefficient was varied by ±1° (without shifting the threshold boundaries for AD, AN, or AP). The mJLO values were then recalculated and compared between groups.

A high degree of correlation between the morphological parameters of the knee joint determined on standard radiographs and those obtained from orthoradiograms was confirmed in the study by M. Unal et al. [18], which served as the rationale for adopting the CPAK model as the prototype.

Additionally, the predictive value of the identified patellar position parameters for determining the mJLO in knee OA was analyzed.

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

Statistical data processing was performed using Statistica 13 software (TIBCO Software Inc.) and the RStudio environment (R version 4.3.3; RStudio, PBC). Descriptive statistical methods were applied for the assessment and analysis of quantitative data. Quantitative variables are presented as mean ± standard deviation (M ± SD). Categorical variables are expressed as absolute counts (n) and corresponding percentages (%).

For comparisons between independent groups, the nonparametric Kruskal–Wallis test was used. The functional relationship between variables was assessed using Kendall's rank correlation coefficient (τ). The predictive value of the analyzed parameters for determining the mJLO in knee OA was evaluated using a binary logistic regression model, with odds ratios (OR) and 95 % confidence intervals (CI) calculated. To minimize potential bias associated with group imbalance and the presence of rare events in the model, Firth's penalized likelihood estimation method was applied, and the results of the logistic regression analysis should be interpreted in an exploratory, hypothesis-generating context. A threshold of $p \leq 0.05$ was used to determine statistical significance.

Table 1. Morphological parameters of patellar position considering the mJLO in knee OA

Parameter		mJLO			p
		AD, n = 43	AN, n = 16	AP, n = 3	
Insall–Salvati ratio	M ± SD	1.23 ± 0.30	1.38 ± 0.27	1.34 ± 0.13	0.04*
	<0.8	0 (0.00 %)	0 (0.00 %)	0 (0.00 %)	1.00
	0.8–1.2	27 (62.79 %)	5 (31.25 %)	0 (0.00 %)	0.02*
	>1.2	16 (37.21 %)	11 (68.75 %)	3 (100.00 %)	0.02*
Caton–Deschamps index	M ± SD	0.75 ± 0.19	0.80 ± 0.27	1.23 ± 0.02	0.01*
	<0.6	12 (27.91 %)	4 (25.00 %)	0 (0.00 %)	0.57
	0.6–1.2	31 (72.09 %)	12 (75.00 %)	0 (0.00 %)	0.03*
	>1.2	0 (0.00 %)	0 (0.00 %)	3 (100.00 %)	<0.00001*
Grelsamer–Meadows index	M ± SD	1.83 ± 0.34	2.06 ± 0.53	2.42 ± 0.62	0.07
	<2	27 (62.79 %)	5 (31.25 %)	0 (0.00 %)	0.02*
	>2	16 (37.21 %)	11 (68.75 %)	3 (100.00 %)	0.02*
Blackburne–Peel ratio	M ± SD	0.64 ± 0.20	0.75 ± 0.28	1.08 ± 0.04	0.01*
	<0.8	34 (79.07 %)	9 (56.25 %)	0 (0.00 %)	0.007*
	0.8–1.0	9 (20.93 %)	3 (18.75 %)	0 (0.00 %)	0.68
	>1.0	0 (0.00 %)	4 (25.00 %)	3 (100.00 %)	<0.00001*

*: a statistically significant difference was observed at $p \leq 0.05$.

Since this was a cross-sectional study including all available cases of medial knee OA suitable for analysis, statistical power was calculated retrospectively. A post hoc power analysis was performed using a parametric one-way analysis of variance (ANOVA) model to approximately assess the adequacy of the sample size. Although nonparametric tests were used in comparative analysis, the ANOVA model was applied for an approximate estimation of effect size and statistical power. The calculations were performed using the G*Power software package (version 3.1; Heinrich Heine University Düsseldorf, Germany). The analysis included three independent groups (n (AD) = 43, n (AN) = 16, n (AP) = 3) with corresponding mean mJLO values (172.40°, 179.25°, and 187.33°) and a pooled standard deviation (SD) of 5.41. The effect size was f = 0.83, which corresponds to a large effect according to Cohen's criteria. At a significance level of $\alpha = 0.05$, the achieved power was 0.9999 (99.99 %), indicating an adequate sample size to detect intergroup differences at the observed effect level.

The study was conducted in accordance with the ethical principles of the Declaration of Helsinki of the World Medical Association (WMA) – Ethical Principles for Medical Research Involving Human Subjects (Seventh Revision, adopted at the 64th WMA General Assembly, Fortaleza, Brazil, October 2013) [19], the Council of Europe Convention on Human Rights and Biomedicine (Oviedo, Spain, April 4, 1997) [20], the applicable national ethical standards [21], and was approved by the Bioethics Committee of the "Angels Clinic" Medical Center, Vinnytsia (Protocol No. 11 dated November 11, 2025). All participants were informed about their involvement in the study, as confirmed by written informed consent forms. The personal data of the examined patients were anonymized to ensure confidentiality.

Results

When assessing the mJLO values, the majority of participants – 69.35 % were classified as having AD, 25.81 % as AN, and 4.84 % as AP. The mean mJLO in the study group was 174.89 ± 5.41°. The mean mJLO value among patients with AD was 172.40 ± 4.05°, among those with AN – 179.25 ± 1.81°, and among those with AP – 187.33 ± 2.52°. The difference between groups was statistically significant ($p < 0.00001$). The differences in indicators between the formed groups remained consistent across all variants of the correction coefficient (5°, 6°, 7°), indicating the stability of the model.

Analysis of the Insall–Salvati ratio in the study group showed a mean value of 1.28 ± 0.29. The highest mean ratios were observed in individuals with AN and in those with AP, while the lowest values were recorded in patients with AD; these differences were statistically significant *(Table 1)*. A direct weak correlation was found between the Insall–Salvati ratio and mJLO values ($\tau = +0.24$, $p = 0.006$), indicating significantly higher index values in individuals with a more proximal orientation of the knee joint line.

According to the performed calculations, Insall–Salvati ratio values <0.8 and, accordingly, signs of patella baja were absent in all examined individuals. Ratio values within the reference range were recorded in patients with AD and AN; among individuals with AP, Insall–Salvati ratio values between 0.8 and 1.2 were not observed. The difference between groups was statistically significant. Signs of patella alta were found in all patients with AP, in the majority of those with AN, and in a substantial proportion of patients with AD; these differences were statistically significant *(Fig. 1)*.

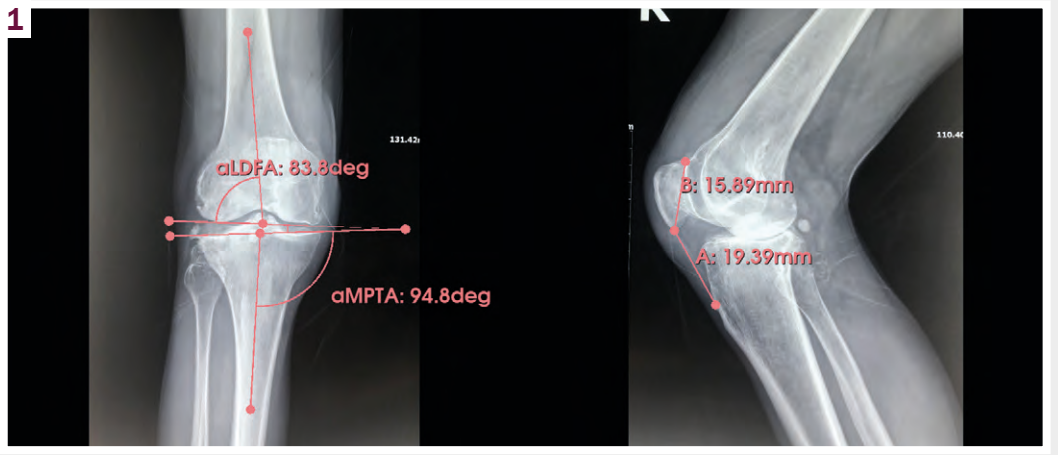

Fig. 1. Anteroposterior and lateral X-rays demonstrating medial knee osteoarthritis, grade 3. mJLO = 83.8° + 94.8° + 6° = 184.6°, indicating AP. Insall–Salvati ratio A : B = 19.39 : 15.89 = 1.22, indicating patella alta.

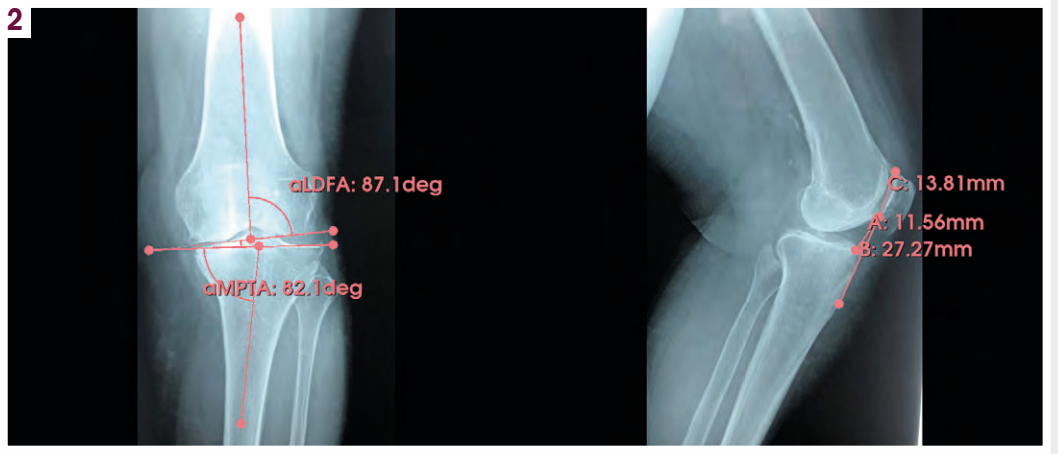

Fig. 2. Anteroposterior and lateral X-rays demonstrating medial knee osteoarthritis, grade 3. mJLO = 87.1° + 82.1° + 6° = 175.2°, indicating AD. Caton–Deschamps index A : C = 11.56 : 13.81 = 0.84, indicating patella norma. Grelsamer–Meadows index B : C = 27.27 : 13.81 = 1.97, indicating patella norma.

The mean Caton–Deschamps index value was 0.79 ± 0.23. The highest index values were observed in individuals with AP, the lowest in those with AD, and intermediate values were found among patients with AN; the difference was statistically significant. Moreover, a direct weak correlation was established between the Caton–Deschamps index and mJLO values (τ = +0.18, p = 0.04), indicating significantly higher index values in individuals with a more proximal orientation of the articular surface apex.

Index values <0.6, corresponding to a low patellar position, were observed in the AD and AN groups, while no such cases were recorded in the AP group; the difference was statistically non-significant. Index values within the range of 0.6–1.2, indicating a normal patellar position, were found in the majority of individuals with AD and AN, whereas no such values were observed in the AP group; this difference was statistically significant *(Fig. 2)*. Index values >1.2, indicative of a high patellar position, were observed in all patients with AP, and not recorded in any individuals from the other groups; the difference was statistically significant.

When analyzing the Grelsamer–Meadows index values among the examined patients, the mean value was 1.92 ± 0.43. The highest index values were found in individuals with AP, the lowest in those with AD, and intermediate values were recorded in patients with AN; however, no statistically significant difference was observed between the groups. Nevertheless, a statistically significant direct weak correlation was found between the Grelsamer–Meadows index and mJLO values (τ = +0.23, p = 0.009), indicating higher index values in patients with a more proximal orientation of the knee joint line.

Grelsamer–Meadows index values <2 were found in the majority of patients with AD and in a smaller proportion of those with AN, while no such values were observed in individuals with AP; the difference in frequency indicators was statistically significant. Signs of patella alta were recorded in all patients with AP, in most individuals with AN, and in a considerable proportion of patients with AD; this difference was statistically significant.

The mean Blackburne–Peel ratio among the examined patients was 0.69 ± 0.24. The highest Blackburne–Peel ratio values

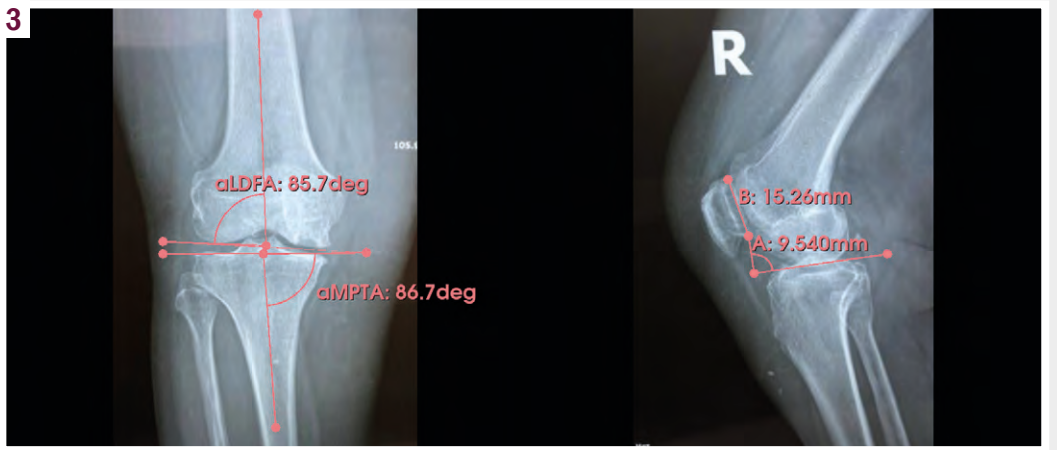

Fig. 3. Anteroposterior and lateral X-rays demonstrating medial knee osteoarthritis, grade 3. mJLO = 85.7° + 86.7° + 6° = 178.4°, indicating AN. Blackburne–Peel ratio A : B = 9.54 : 15.26 = 0.63, indicating patella baja.

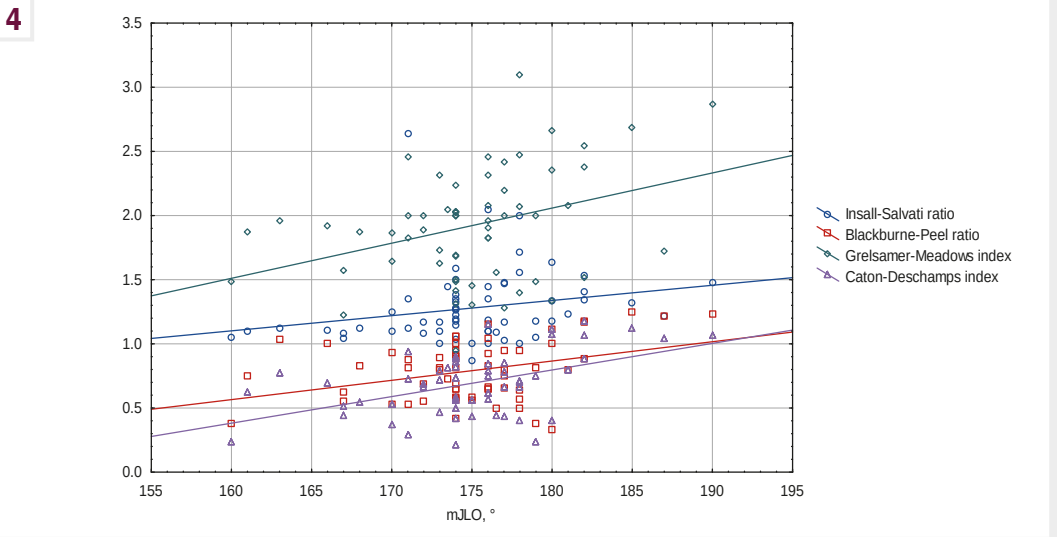

Fig. 4. Scatter plot of patellar position indices in relation to mJLO in patients with knee osteoarthritis.

were observed in individuals with AP, the lowest in those with AD, while patients with AN demonstrated intermediate values. Comparison of the results among the groups, formed according to the mJLO, revealed a statistically significant difference. Furthermore, significantly higher Blackburne–Peel ratio values in patients with a more proximal orientation of the knee joint line were confirmed by the presence of a statistically significant direct correlation between the index values and the mJLO angle ($\tau = +0.27$, $p = 0.002$).

Blackburne–Peel ratio values <0.8, corresponding to signs of patella baja, were observed in the majority of patients with AD and AN, while no such cases were recorded in individuals with AP; the difference was statistically significant with a high degree of confidence *(Fig. 3)*. Blackburne–Peel ratio values of 0.8–1.0, corresponding to a normal patellar position, were observed in patients with AD and AN, while no such values were recorded in the AP group; the difference in frequency indicators was not statistically significant. Signs of patella alta, according to the Blackburne–Peel ratio, were found in all individuals with AP and in a minority of patients with AN, whereas values >1.0 were not observed in the AD group; the difference was statistically significant with a high degree of confidence.

The relationships between the values of the examined patellar position indices and mJLO are shown in *Fig. 4*.

When analyzing the predictive value of the examined indices in determining mJLO in knee OA, significantly higher odds of developing AD were found in the presence of Insall–Salvati ratio values of 0.8–1.2, whereas values >1.2 were associated with significantly lower odds of this joint line orientation type *(Table 2)*.

The presence of signs of a high patellar position, reflected by Caton–Deschamps index values >1.2, was associated with a lower probability of AD formation and significantly higher odds of AP; however, the wide confidence interval in the latter case indicates instability of the obtained result. In addition, a lower probability of AP was observed in individuals with Caton–Deschamps index values within the reference range.

Among individuals with Grelsamer–Meadows index values <2, significantly higher odds of AD formation were demonstrated,

Table 2. Predictive values of morphological parameters of patellar position in determining the mJLO in knee OA

Parameter		mJLO		
		AD	AN	AP
Insall–Salvati ratio	0.8–1.2	OR = 4.39	OR = 0.34	OR = 0.12
		CI (1.44–15.02)	CI (0.10–1.06)	CI (0.0009–1.3300)
		p = 0.009	p = 0.06	p = 0.09
	>1.2	OR = 0.23	OR = 2.95	OR = 8.27
		CI (0.07–0.69)	CI (0.95–10.15)	CI (0.75–1130.97)
		p = 0.009	p = 0.06	p = 0.09
Caton–Deschamps index	<0.6	OR = 1.37	OR = 0.99	OR=0.38
		CI (0.41–5.16)	CI (0.26–3.36)	CI (0.003–4.200)
		p = 0.62	p = 0.99	p = 0.48
	0.6–1.2	OR = 1.51	OR = 1.37	OR = 0.05
		CI (0.48–4.62)	CI (0.41–5.16)	CI (0.0004–0.6000)
		p = 0.47	p = 0.62	p = 0.02
	>1.2	OR = 0.05	OR = 0.38	OR = 833.00
		CI (0.0004–0.60)	CI (0.003–4.20)	CI (32.60–273970.85)
		p = 0.02	p = 0.48	p = 0.000004
Grelsamer–Meadows index	<2	OR = 4.39	OR = 0.34	OR=0.12
		CI (1.44–15.02)	CI (0.10–1.06)	CI (0.0009–1.3300)
		p = 0.009	p = 0.06	p = 0.09
	>2	OR = 0.23	OR = 2.95	OR = 8.27
		CI (0.07–0.69)	CI (0.95–10.15)	CI (0.75–1130.97)
		p = 0.009	p = 0.06	p = 0.09
Blackburne–Peel ratio	<0.8	OR = 4.01	OR = 0.46	OR = 0.05
		CI (1.31–12.89)	CI (0.14–1.48)	CI (0.0004–0.6000)
		p = 0.02	p = 0.19	p = 0.02
	0.8–1.0	OR = 1.30	OR = 1.02	OR = 0.54
		CI (0.35–5.76)	CI (0.23–3.83)	CI (0.004–6.160)
		p = 0.70	p = 0.97	p = 0.67
	>1.0	OR = 0.02	OR = 4.47	OR = 86.33
		CI (0.0001–0.1800)	CI (0.96–22.58)	CI (6.90–12346.04)
		p = 0.00005	p = 0.06	p = 0.0003

whereas index values >2 were associated with significantly lower odds of developing this joint line orientation.

In patients with a Blackburne–Peel ratio <0.8, and accordingly with signs of patella baja, significantly higher odds of AD were demonstrated, whereas a ratio >1.0 was associated with a lower probability of developing this type of joint line inclination. Significantly higher odds of AP were observed in subjects with a Blackburne–Peel ratio >1.0; however, the wide confidence interval indicates instability of this finding. Conversely, a ratio <0.8 was associated with a significantly lower likelihood of AP.

Discussion

An analysis of the morphological parameters of patellar position in patients with knee OA demonstrated significant differences depending on the mJLO as determined by the original method.

In the present study, the majority of patients with knee OA exhibited AD, whereas AN and AP orientations were observed much less frequently. Despite methodological differences in measurement, the clear predominance of distal joint line orientation, according to the CPAK classification, in the OA population has been confirmed by several studies. Specifically, in the original multicenter

study by S. J. MacDessi et al., AD was identified in 67 % (n = 500) of patients with knee OA [17]; in the study by S. E. Kim et al., AD was observed in 67.1 % (n = 164) [22]; and in the study by S. Agarwal et al., AD was reported in 66.41 % of cases (n = 134) [23].

The mean mJLO value in the studied cohort was consistent with the data presented by L. E. Corban et al., who reported a mean JLO of 174.7 ± 3.3° in patients with knee OA [24], as well as with the findings of A. Şenel et al. [25] and S. E. Kim et al. [22], who determined mean JLO values of 174.6 ± 3.7° and 175.8 ± 2.9°, respectively.

The lowest mean mJLO values in the studied cohort were observed in individuals with AD, while the highest were found in patients with AP, and intermediate values were recorded in those with AN. The stability of intergroup differences in mJLO persisted when the correction coefficient of "+6°" was varied within ±1°, indicating a high robustness of the calculated parameters, the internal consistency of the method, and correctness of the applied formula, even in the presence of minor measurement errors and without direct validation using long-leg radiographs.

A similar trend in the variation of the analyzed angles depending on joint line inclination was noted by L. E. Corban et al., who, analyzing knee phenotypes according to the CPAK classification in 643 patients with OA (n = 700 knees), reported mean JLO values of 173.3 ± 2.4° in the AD group (76.3 %), 178.9 ± 1.4° in the AN group (23.0 %), and the highest values in patients with AP (0.7 %) – 184.4 ± 1.2° [24].

Based on the evaluation of the Insall–Salvati, Caton–Deschamps, Grelsamer–Meadows, and Blackburne–Peel indices, signs of patella alta were more frequently observed in cases of AP. Conversely, in patients with AD and AN, normal or low patellar height was more commonly recorded. The identified weak positive correlations between patellar height indices and mJLO values indicate the existence of a structural and biomechanical relationship between joint line orientation and the positioning of the patellofemoral joint.

According to the results of the prognostic analysis, Insall–Salvati ratio values in the range of 0.8–1.2, Grelsamer–Meadows index <2, and Blackburne–Peel ratio <0.8 were significantly associated with higher odds of AD formation. In contrast, the presence of patella alta was significantly associated with higher odds of AP. It should be noted that Caton–Deschamps index values >1.2 and Blackburne–Peel ratio >1.0 were formally identified as statistically significant predictors of AP; however, considering the limited number of cases (n = 3) and indications of perfect separation leading to model instability, these results should be interpreted with caution. The relationship between these parameters requires further investigation.

No studies directly examining the relationship between patellar position and the JLO were found. However, several studies have demonstrated an association between the development and progression of knee OA and abnormal patellar positioning.

Patella alta is considered a significant risk factor for patellofemoral instability, increased contact stresses on the lateral facet, and the progression of degenerative changes [26,27]. Some evidence also indicates an association between high patellar position and fat pad edema, suggesting a possible involvement of inflammatory mechanisms as part of the OA pathogenesis [27].

In particular, Y. Wang et al. [27] found that the risk of developing knee OA in patients with patella alta was approximately 2.2 times higher compared to those with normal patellar positioning. In a case-control study based on magnetic resonance imaging data from 80 individuals (40 patients with knee OA and 40 subjects without signs of the disease), the researchers reported a significantly higher frequency of patella alta among patients with knee OA – 15 (37.5 %) compared with 7 (17.5 %) in the control group (p = 0.045).

A high prevalence of abnormal patellar positioning was also reported in a retrospective cross-sectional study by F. Z. Arslan and G. Y. Oğuzdoğan, who analyzed magnetic resonance imaging data from 446 patients with chronic anterior knee pain. Pathological Insall–Salvati ratio values were identified in 205 (45.96 %) patients, including 125 (28.02 %) with a ratio >1.3 and 80 (17.94 %) with a ratio <0.8, while the majority – 241 (54.04 %) – had values within the reference range [28].

It is worth noting the slightly higher frequency of patella alta among our patients compared to the aforementioned data, which can be attributed to differences in measurement techniques and threshold criteria for defining high patellar position. However, our findings are consistent with the results of the retrospective study by P. D. Analan et al., who, analyzing radiographic examinations of 45 patients with stage 2–3 knee OA (n = 62 knees), identified patella alta based on the Insall–Salvati ratio in 15 (24.2 %) individuals, patella baja in 2 (3.2 %), and patella norma in the majority – 45 (72.6 %) of cases [29].

The mean Caton–Deschamps index determined in our patients with medial OA was within the reference range, which is consistent with findings from contemporary studies. According to R. D'Ambrosi et al. [30], the mean Caton–Deschamps index in patients with medial gonarthrosis was 0.97 ± 0.15; in the study by K. S. Sahanand et al. [31] it was 0.93 ± 0.45; and Y. Kudo et al. [32] reported 0.92 ± 0.12. It should be noted that the mean Caton–Deschamps index established in our cohort was slightly lower, which may be attributed to degenerative and dystrophic changes of the articular surface in the proximal tibia. In the comparative studies cited above, degenerative changes in the examined patients' knee joints were less pronounced, which should be considered when interpreting and comparing the indices.

The mean Grelsamer–Meadows index in our patients also corresponded to the reference range. These findings are consistent with the results of F. Luceri et al. [33], who reported a modified Insall–Salvati index value of 1.6 ± 0.31, and J. A. Sim et al. [34], who found a value of 1.36 ± 0.14 when analyzing radiographic parameters used to assess patellar position in patients with medial knee OA.

In contrast, the mean Blackburne–Peel ratio in our cohort indicated a low patellar position. Similar findings were presented by J. A. Sim et al. [34], who reported a mean Blackburne–Peel index of 0.63 ± 0.14 in patients with medial knee OA with varus deformity greater than 5° (n = 56 knees).

In our opinion, the use of the Insall–Salvati ratio and the Grelsamer–Meadows index is more reliable for assessing patellar position in patients with knee OA and AD, considering that the tibial tuberosity – which serves as a reference point for these measurements – is less affected by pathological changes in such cases. Conversely, the Caton–Deschamps index and the Black-

burne–Peel ratio provide more accurate assessments of patellar position in individuals with knee OA and AP, indirectly indicating a lower degree of structural alteration in the articular surface of the proximal tibia, which serves as the reference structure for these measurements.

Thus, the obtained results indicate the presence of a structural and biomechanical relationship between the obliquity of the articular surface and the positioning of the patellofemoral joint. From a practical standpoint, these findings emphasize the necessity of a comprehensive assessment of morphometric indices of patellar position, which would allow for more accurate stratification of patients by risk of OA progression and support the rationale for selecting the optimal surgical correction strategy, taking into account the inclination of the joint line.

This study had several limitations that should be considered when interpreting the results. The analysis was conducted at the joint level, with both knees of the same patient considered as independent observations. This may affect the precision of standard errors and statistical significance; however, the main patterns are, in our view, likely to remain reliable.

Despite the single-center design of the study, the radiographs were obtained at various medical facilities prior to patient inclusion, which could have affected the standardization of baseline data. Although generally accepted radiographic protocols were followed, the conditions for performing weight-bearing knee radiographs might have differed between institutions. Considering the potential variability in radiographic conditions, preference was given to the analysis of angular morphometric parameters, which are less affected by projection distortions and scaling errors. This approach partially mitigated the influence of technical factors.

Despite the strong correlation between anatomical and mechanical angle values measured on standard anteroposterior knee radiographs and full-length radiographs [18], the absence of internal validation using full-length images remains a study limitation that warrants further verification in future research. In particular, the proposed mJLO formula requires dedicated validation against mechanically measured joint line orientation on full-length standing radiographs, including agreement analysis (for example, Bland–Altman) and correlation testing, which was beyond the scope of the present study.

Patellar position indices were analyzed separately without correction for multiple comparisons, as the study was focused on evaluating individual parameters within groups formed according to mJLO, rather than assessing a cumulative effect. This approach may increase the risk of a type I error, which should be taken into account when interpreting the findings.

Conclusions

1. Morphological parameters of patellar position demonstrate significant variation depending on knee joint line obliquity in patients with medial knee osteoarthritis, as determined using the authors' method.

2. A more proximally oriented joint line is associated with a consistently higher patellar position, confirming the presence of a structural and biomechanical relationship between joint line inclination and patellofemoral alignment.

3. Patients with apex distal predominantly exhibit normal or low patellar height, whereas those with apex proximal are characterized by a predominance of patella alta, and individuals with apex neutral demonstrate intermediate morphological features.

4. Overall, the morphological parameters of patellar position serve as sensitive markers of biomechanical alterations in knee osteoarthritis associated with variations in joint line obliquity. These findings support the inclusion of patellar height assessment in comprehensive radiographic evaluation of patients prior to surgical planning and rehabilitation.

Prospects for further research. A promising direction is the comparative analysis and assessment of agreement between mJLO measurements, determined using the original method, and JLO values calculated according to the CPAK methodology. In the future, the results of this study may be used for clinical stratification of patients with medial gonarthrosis, enabling a more personalized approach to the rational planning of corrective osteotomy and knee arthroplasty, taking into account individual anatomical parameters. Another avenue for further research is the prospective validation of a model assessing the ability of the mJLO index to predict clinical course of osteoarthritis, including pain intensity and functional changes, as well as guiding the selection of the optimal reconstructive intervention based on the individual structural characteristics of the knee joint. Considering that four patellar position indices were analyzed in this study, it is also promising to apply corrections for multiple comparisons, evaluate the cumulative effect, and determine the hierarchy of the examined parameters. From a practical standpoint, the assessment of mJLO and patellar height indices could be incorporated into preoperative radiometric mapping, potentially aiding the prediction of patellofemoral joint load and the risk of patella alta or pseudo-baja during corrective interventions. In the planning of osteotomies or partial/total knee arthroplasty, avoiding an excessive increase in joint line inclination may help reduce shear forces and optimize patellar mechanics. These considerations represent potential clinical applications of the study findings and warrant further investigation in prospective studies.

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