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## ABSTRACT

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## MORPHOLOGICAL VARIATION OF KNEE JOINTS IN DEGENERATIVE-DYSTROPHIC DISEASES

**Introduction.** Structural differences in knee joints associated with sex, height, body weight, individual characteristics and ethnic origin have been confirmed by numerous studies. However, the issue of segmenting a heterogeneous population of patients with degenerative-dystrophic knee joint diseases remains unresolved. Understanding the morphological variability of knee joints may contribute to improving orthopedic intervention techniques in line with the principles of personalized surgery and enhancing clinical outcomes in patients with degenerative-dystrophic knee conditions. *Aim:* To characterize the prevalence of morphological variants of the knee joint in patients with degenerative-dystrophic diseases, based on a modified Coronal Plane Alignment of the Knee (CPAK) classification and a custom clustering system.

**Materials and Methods.** Radiographic examination of 100 cases of degenerative medial knee joint disease were analyzed. The average age was  $63.56 \pm 8.10$  years. The structural variants of the knee joint were assessed using a modified CPAK classification and a custom clustering system. Based on the clustering of morphometric indicators, morphotype I was identified in 21 patients (21.00 %), morphotype II in 38 patients (38.00 %), morphotype III in 29 patients (29.00 %), and morphotype IV in 12 patients (12.00 %). Statistical analysis was conducted using Statistica 13 software, with a significance level set at  $p \leq 0.05$ .

**Results.** The mean value of the modified joint line orientation (mJLO) in the examined patients was  $174.28 \pm 5.20^\circ$ , and the mean arithmetic hip-knee-ankle angle (aHKA) was  $0.19 \pm 4.74^\circ$ , indicating a predominantly distal orientation of the joint line and neutral lower limb alignment in patients with degenerative-dystrophic knee diseases. A distal apex of the joint line was observed in 72 patients (72.00 %), a neutral position in 25 patients (25.00 %), and a proximal position in 3 individuals (3.00 %). aHKA values  $< -2^\circ$  were recorded in 35 patients

(35.00 %), values within  $\pm 2^\circ$  in 41 patients (41.00 %), and values  $> 2^\circ$  in 24 patients (24.00%). According to the modified CPAK classification, the most common knee joint types were type I (30.00 %), type II (28.00 %), and type III (14.00 %).

**Conclusion.** The study confirmed the morphological variability of knee joints in degenerative-dystrophic diseases.

**Keywords:** knee joint, degenerative-dystrophic diseases, osteoarthritis, diagnosis, morphology, classification, gonarthrosis.

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## МОРФОЛОГІЧНА ВАРІАБЕЛЬНІСТЬ КОЛІННИХ СУГЛОБІВ ПРИ ДЕГЕНЕРАТИВНО-ДИСТРОФІЧНИХ ЗАХВОРЮВАННЯХ

**Вступ.** Структурні відмінності колінних суглобів, зумовлені статтю, зростом, масою тіла, етнічним походженням підтверджені результатами численних досліджень, проте проблема сегментації гетерогенної популяції пацієнтів з дегенеративно-дистрофічними захворюваннями колінного суглоба залишаються невирішеною. Розуміння морфологічної варіабельності колінних суглобів дозволить удосконалити методики ортопедичних втручань з урахуванням принципів персоналізованої хірургії та покращити клінічні результати лікування пацієнтів з дегенеративно-дистрофічними захворюваннями колінного суглоба. *Мета:* охарактеризувати поширеність морфологічних варіантів колінного суглобу у пацієнтів з дегенеративно-дистрофічними захворюваннями, відповідно до модифікованої класифікації Coronal Plane Alignment of the Knee (CPAK) та власної кластерної системи.

**Матеріали і методи.** Проаналізовано результати рентгенографічного обстеження 100 випадків дегенеративно-дистрофічного захворювання колінного суглоба з переважним ураженням медіального відділу суглоба. Середній вік –  $63,56 \pm 8,10$  років. Для характеристики структурного варіанту колінного суглоба використовували класифікацію CPAK з модифікаціями та власну кластерну систему. Шляхом кластеризації морфометричних показників морфотип I колінного суглоба встановлено у 21 (21,00 %) пацієнта, морфотип II – у 38 (38,00 %), у 29 (29,00 %) обстежених зафіксовано морфотип III, ще у 12 (12,00 %) – морфотип IV. Статистичний аналіз виконували з використанням програмного засобу Statistica 13. Рівень статистичної значущості визначали при  $p \leq 0,05$ .

**Результати.** Середній показник модифікованого показника положення верхівки суглоба (mJLO) у обстежених хворих становив  $174,28 \pm 5,20^\circ$ , а середнє значення арифметичного стегново-колінно-гомількового кута (аНКА) –  $0,19 \pm 4,74^\circ$ , що свідчить про переважно дистальну орієнтацію суглобової лінії та нейтральне положення осі нижньої кінцівки у пацієнтів з дегенеративно-дистрофічними захворюваннями колінного суглоба. Дистальне положення верхівки суглоба спостерігали у 72 (72,00 %) обстежених, нейтральне – у 25 (25,00 %), у 3 (3,00%) осіб – проксимальне. Значення аНКА  $< -2^\circ$  встановлено у 35 (35,00 %) обстежених, аНКА  $\pm 2^\circ$  – у 41 (41,00 %), показники аНКА  $> 2^\circ$  спостерігали у 24 (24,00 %) хворих. Найбільш

поширеними типами колінних суглобів, встановленими відповідно до модифікованої версії класифікації CPAK, були типи I (30,00 %), II (28,00 %) та III (14,00 %).

**Висновок.** В результаті проведеного дослідження нами підтверджено морфологічну варіабельність колінних суглобів при дегенеративно-дистрофічних захворюваннях.

**Ключові слова:** колінний суглоб, дегенеративно-дистрофічні захворювання, остеоартроз, діагностика, морфологія, класифікація, гонартроз.

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## ABBREVIATIONS

AD (Apex Distal) – distal position of the joint apex; aHKA – arithmetic hip-knee-ankle angle; AN (Apex Neutral) – neutral position of the joint apex; AP (Apex Proximal) – proximal position of the joint apex; CI – 95% confidence interval; CPAK – coronal plane alignment of the knee; FTA – femoral-tibial angle; JLO – joint line orientation; LDFA – lateral distal femoral angle; mJLO – modified joint line orientation; MPTA – medial proximal tibial angle; OR – odds ratio

## INTRODUCTION

A pressing task of modern orthopedics is the study of the knee joint morphological heterogeneity in degenerative-dystrophic diseases of the musculoskeletal system.

Structural differences in knee joints due to gender, height, body weight, individual characteristics, and ethnic origin of individuals have been confirmed by the results of numerous studies [1, 2, 3]. In addition, the heterogeneity of clinical symptoms of osteoarthritis has been proven, taking into account the variation of femur and tibia morphology [4, 5].

Despite the great attention of scientists to this issue, the problem of phenotyping a heterogeneous population of patients with degenerative-dystrophic diseases of the knee joint remains unresolved [6, 7]. In this context, the use of personalized medicine approaches considering the individual morphofunctional characteristics of the patient is becoming increasingly relevant.

One of the modern tools for analyzing the morphological variation of knee joints is the Coronal Plane Alignment of the Knee (CPAK) classification [8]. Using the CPAK classification helps to systematize the types of knee joints, taking into account the orientation of the joint line and the position of the lower limb axis. In addition, the CPAK classification is a comprehensive prognostic tool for determining pre-arthritis features of the knee joint structure, which can be used both in healthy individuals and in patients with degenerative-dystrophic diseases [3, 8]. It is worth noting that the use of this classification has a number of limitations. In particular, performing orthoradiographs, which is a prerequisite for using CPAK, is not always available in daily clinical practice. In addition, the classification

does not take into account morphological parameters in the sagittal plane as well as individual patient factors, and is unsuitable in cases of segmental extra-articular deformities [9]. The issue of geographical variation of knee joint morphology and the reasonability of using the classification in different ethnic groups remains insufficiently studied.

In a systematic review, Pagan et al. (2023) presented an analysis of the results of 7 studies that examined the geographical variation of knee joint phenotypes according to CPAK in 2804 patients with osteoarthritis. The researchers found that CPAK type I was the most common type of knee joint in France (33.4%), India (58.8%), and Japan (53.8%), while patients from Australia had a higher frequency of CPAK type II (32.8% of cases). The difference in prevalence of CPAK I and II types in the considered geographical regions was statistically significant ( $p < 0.01$ ) [2].

According to a study by Hsu et al. (2022), characteristic features of knee joint morphology for the Asian population are a higher frequency of varus types and a wider distribution in lower limb alignment. The scientists associated these changes with genetic factors, cultural characteristics, and the peculiarities of physical load on the lower extremities [3].

Thus, the results of international studies indicate ethnic variation in structural variants of the knee joint in patients with degenerative-dystrophic diseases and significant differences in the distribution of joint types according to CPAK, taking into account the geographical factor. There is no information on the morphological variation of knee joints in the Ukrainian population. Widespread use of the CPAK system for knee joint types classification is not available due to the

limited use of orthoradiographs in surgical interventions. However, understanding the morphological variation of knee joints in degenerative-dystrophic diseases will help to improve existing methods of corrective osteotomy of the femur and tibia, as well as the methods of monocondylar and total arthroplasty with respect to the principles of personalized surgery. At the same time, considering the individual structural features of the knee joint during preoperative planning will improve the clinical results of treatment in patients with degenerative-dystrophic diseases of the knee joint.

**The objective of the study:** to characterize the prevalence of morphological variants of the knee joint in patients with degenerative-dystrophic diseases according to the modified CPAK classification and our own cluster system.

#### MATERIALS AND METHODS

The presented observational cross-sectional study analyzed the results of radiographic examination of 100 cases of degenerative-dystrophic knee joint disease with predominant lesion of the medial joint in 70 patients who were inpatients in the Traumatology Department of the Vinnytsia City Clinical Hospital of Emergency Medicine in 2017–2025. The average age was  $63.56 \pm 8.10$  years. The group included 26 (37.14%) men and 44 (62.86%) women. Signs of unilateral degenerative-dystrophic lesion of the knee joint were detected in 40 (57.14%) patients, and bilateral disease was recorded in 30 (42.86%) of the examined patients.

Inclusion criteria were: primary osteoarthritis of the knee joint of the II-III degree according to the Kellgren-Lawrence classification with a predominant lesion of the medial joint; secondary osteoarthritis of the knee joint with a predominant lesion of the medial joint, including secondary osteoarthritis of the knee joint after aseptic necrosis of the medial condyle of femur; satisfactory condition of the lateral knee joint (intact meniscus and full thickness of the articular cartilage); integrity of the ligamentous apparatus of the knee joint; full extension of the knee joint or flexion contracture  $< 10^\circ$ .

Exclusion criteria were: total degenerative-dystrophic lesion of the medial and lateral knee joints; secondary post-traumatic osteoarthritis after a fracture of the tibial plateau; the history of surgical interventions on the proximal part of the tibia (except for arthroscopic meniscectomy); flexion contracture  $> 10^\circ$ ; instability of the ligamentous apparatus of the knee joint; secondary osteoarthritis caused by dysplastic changes in bone tissue or metabolic and other diseases (ochronosis, Gaucher disease, Paget's disease, osteopetrosis); active infectious process or presence of latent infection.

To characterize the structural variant of the knee joint, the CPAK classification with our own

modifications was used. According to the original methodology proposed by MacDessi et al. (2021), it is necessary to determine two key parameters: the arithmetic hip-knee-ankle angle (aHKA) and the joint line orientation (JLO) [8]. These variables are calculated as the difference or sum of the mechanical lateral distal femoral angle (LDFA) and the mechanical medial proximal tibial angle (MPTA) determined on the lower extremity orthoradiographs.

Since orthoradiography was not available during this study, standard (short) radiographs of the knee joints were used, performed in direct projection with the lower limbs bearing load. A high degree of correlation between morphological parameters of the knee joint found on standard knee joint radiographs performed in anteroposterior projections and orthoradiographs was proven in the study by Unal et al. (2020) [10]. Since we used standard radiographs during the study, anatomical angles were assessed, not mechanical ones. Anatomical LDFA was calculated as the angle between the line connecting the most distal parts of both femoral condyles and the anatomical axis of the femur, measured laterally. The angle between the line tangent to the proximal tibial articular surface and the anatomical axis of the tibia, measured from the medial side, was defined as the anatomical MPTA. The angle between the anatomical axes of the femur and tibia was defined as the femoral-tibial angle (FTA).

The next step was to calculate the modified values of the aHKA and JLO. Thus, aHKA was calculated according to the original methodology:  $aHKA = MPTA - LDFA$ . Modified JLO was calculated according to the formula:  $mJLO = MPTA + LDFA + 6^\circ$ , where  $6^\circ$  = correction factor indicating valgus deviation of the anatomical axis relative to the mechanical axis [11].

The interpretation of the obtained results was carried out in accordance with the recommendations of the original methodology [8]. The varus position of the lower limb axis was defined for aHKA values  $< -2^\circ$ , neutral position – for aHKA values within  $-2^\circ$ – $(+2^\circ)$ , valgus position – for aHKA values  $> +2^\circ$ . The orientation of the joint line was defined as distal (AD (apex distal)) when the mJLO index was  $< 177^\circ$ , as neutral (AN (apex neutral)) when the mJLO corresponded to the range of  $177$ – $183^\circ$ , and as proximal (AP (apex proximal)) when the mJLO  $> 183^\circ$ .

Subsequently, a matrix of joint types was formed, which combined three categories of the lower limb axis position (aHKA): varus, neutral, valgus, and three types of joint line orientation (JLO): distal, neutral, proximal. A total of nine phenotypic knee joint variants were analyzed.

Additionally, the knee joint types were characterized according to our own cluster system. The features of

clustering of knee joint types affected by degenerative-dystrophic processes are presented in our previous work [17].

The presented study was conducted in accordance with the ethical principles of the World Medical Association Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects (Seventh Revision, adopted at the 64th WMA General Assembly, Fortaleza, Brazil, October 2013), the Council of Europe Convention on Human Rights and Biomedicine (Oviedo, Spain, April 4, 1997), as well as in accordance with current national ethical standards. All participants were informed about their participation in the study and provided written informed consent. Patients' personal data were anonymized to ensure confidentiality.

Statistical analysis was performed using Statistica 13 software. Descriptive statistics methods were used to evaluate and analyze quantitative data. Quantitative variables were presented as mean  $\pm$  standard deviation ( $M \pm SD$ ). Categorical variables were presented as the absolute number of observations ( $n$ ) and the corresponding percentage (%). When comparing the indicators of independent groups, the nonparametric Kruskal-Wallis statistical criterion was used; the functional relationship between variables was assessed using the Kendall rank correlation coefficient (Kendall's Tau). The prognostic value of the considered parameters for the determination of the morphological variant of the knee joint affected by the degenerative-dystrophic process was assessed based on the statistical model of binary logistic regression, considering the odds ratio (OR) and 95% confidence intervals (CI). The level of statistical significance was determined at  $p \leq 0.05$ .

## RESULTS

According to our own cluster system, 4 groups were formed from the examined patients, which corresponded to 4 morphological variants of the knee joint structure in degenerative-dystrophic diseases. Morphotype I was detected in 21 (21.00%) patients, morphotype II – in 38 (38.00%) patients, morphotype III – in 29 (29.00%) patients, and morphotype IV – in 12 (12.00%) patients.

The average FTA angle in the examined patients was  $177.09 \pm 5.57^\circ$ . In patients with morphotype I, the average FTA angle was  $169.76 \pm 1.48^\circ$ , which corresponded to varus deviation of the lower limb axis. Varus deviation of the axis was also recorded in patients with morphotype II, whose average FTA angle was  $175.58 \pm 1.32^\circ$ . In the examined patients with morphotype III, the average FTA angle was  $180.14 \pm 1.49^\circ$  and corresponded to the neutral position of the lower limb axis. In individuals with morphotype IV, the average value of the studied angle was  $187.33 \pm 3.75^\circ$ , which corresponded to valgus deviation of the axis. When comparing the average values of the FTA angle in the formed groups, the difference was statistically significant ( $p < 0.0001$ ).

The average mJLO index in the subjects was  $174.28 \pm 5.20^\circ$ . In individuals with knee joint morphotype I, the average mJLO index was  $170.14 \pm 5.62^\circ$ , in patients with morphotype II –  $174.71 \pm 4.11^\circ$ , in patients with type III –  $175.07 \pm 4.21^\circ$ , and in those with knee joint morphotype IV –  $178.25 \pm 5.63^\circ$ ; the difference was statistically significant ( $p = 0.004$ ) (Table 1). A direct weak correlation was demonstrated between FTA indicators and mJLO values ( $\tau = +0.21$ ,  $p = 0.002$ ), indicating a higher frequency of proximal joint line orientation in patients with valgus deviation of the lower limb axis.

**Table 1 – mJLO and aHKA characteristics with regard to the knee joint morphotype**

	Variants of knee joint morphotypes				p
	I (n=21)	II (n=38)	III (n=29)	IV (n=12)	
mJLO	$170.14 \pm 5.62$	$174.71 \pm 4.11$	$175.07 \pm 4.21$	$178.25 \pm 5.63$	0.004*
AD	21 (100.00%)	26 (68.42%)	20 (68.97%)	5 (41.67%)	0.003*
AN	0 (0.00 %)	12 (31.58%)	8 (27.59%)	5 (41.67%)	0.02*
AP	0 (0.00 %)	0 (0.00 %)	1 (3.44%)	2 (16.66%)	0.02*
aHKA	$-5.0 \pm 1.52^\circ$	$-1.67 \pm 2.24^\circ$	$2.55 \pm 1.40^\circ$	$9.42 \pm 2.27^\circ$	$< 0.00001^*$
$< -2^\circ$	21 (100.00%)	14 (36.84%)	0 (0.00 %)	0 (0.00 %)	$< 0.00001^*$
$\pm 2^\circ$	0 (0.00 %)	23 (60.53%)	18 (62.07%)	0 (0.00 %)	$< 0.00001^*$
$> 2^\circ$	0 (0.00 %)	1 (2.63%)	11 (37.93%)	12 (100.00%)	$< 0.00001^*$

Note: \* – a difference in indicators was statistically significant at  $p \leq 0.05$

According to the established mJLO values, the vast majority of the examined subjects, 72 (72.00%), had a distal position of the joint apex, 25 (25.00%) – neutral joint apex, and 3 (3.00%) – proximal joint apex.

The distal apex position was established in all patients with knee joint morphotype I – 21 (100.00%) subjects, and in the vast majority of patients with morphotype II and III – 26 (68.42%) and 20 (68.97%) subjects, respectively. In addition, the indicated position was observed in 5 (41.67%) patients with morphotype IV; the difference in indicators was statistically significant ( $p=0.003$ ).

The neutral position of the joint apex was recorded in 5 (41.67%) patients with morphotype IV, 8 (27.59%) patients with morphotype III, and 12 (31.58%) patients with morphotype II. The neutral position of the joint apex was not observed in the group of morphotype I. The difference in the studied frequency indicators was statistically significant ( $p=0.02$ ).

The proximal joint apex position was observed in 2 (16.66%) patients with morphotype IV and 1 (3.44%) patient with morphotype III. In cases of varus deviation of the lower limb axis, the proximal position of the joint apex was not observed in knee joint morphotypes I and II. The difference in indicators was statistically significant ( $p=0.02$ ).

The calculated average aHKA angle in the subjects was  $0.19 \pm 4.74^\circ$ . The specified angle was  $(-5.0 \pm 1.52^\circ)$  in patients with morphotype I,  $(-1.67 \pm 2.24^\circ)$  – in patients with morphotype II,  $(2.55 \pm 1.40^\circ)$  – in patients with morphotype III, and  $(9.42 \pm 2.27^\circ)$  – in patients with morphotype IV; the difference in the values of the aHKA angle in the formed groups was statistically significant ( $p < 0.00001$ ). A direct strong correlation was demonstrated between FTA indicators and aHKA angle values ( $\tau = +0.82$ ,  $p < 0.00001$ ).

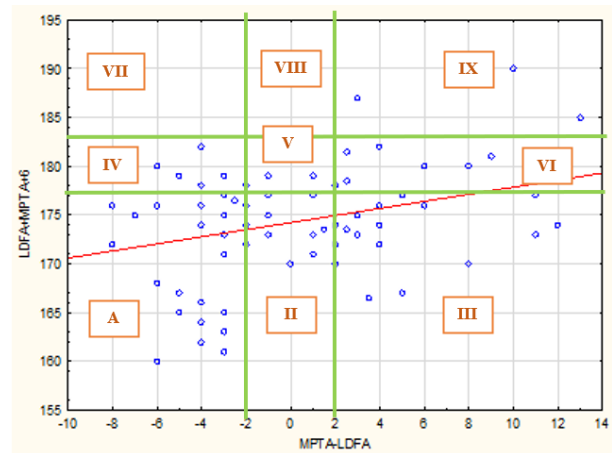
The value of aHKA  $< -2^\circ$  was found in 35 (35.00%) subjects. These indicators were observed in all patients with morphotype I – 21 (100.00%) and in 14 (36.84%) patients with morphotype II. In individuals with neutral and valgus deviation of the lower limb axis and morphotypes III and IV, respectively, these indicators were not recorded.

aHKA values of  $\pm 2^\circ$  were observed in 41 (41.00%) patients of the group: in the vast majority of those with morphotype II – 23 (60.53%) and III – 18 (62.07%). However, these indicators were not recorded in individuals with morphotypes I and IV.

aHKA values of  $> 2^\circ$  were observed in 24 (24.00%) examined subjects. These indicators were recorded in all 12 patients with valgus deviation of the axis

(100.00%), 11 (37.93%) people with morphotype III, and 1 (2.63%) subject with morphotype II.

The characteristics of the distribution of patients according to the CPAK classification, taking into account our own modifications, are shown in Figure 1.



**Figure 1 – Scatter plot of aHKA and mJLO in the examined patients**

The type frequency in groups formed according to the morphological features of the knee joint structure in degenerative-dystrophic diseases is given in Table 2.

Type I was observed in 30 (30.00%) subjects and in 85.71% (30/35) of the knee joints with varus deviation of the lower limb axis. The specified type was reported in all patients with morphotype I – 21 (100.0%) cases and in 9 (23.68%) individuals with morphotype II; in the patients with morphotypes III and IV, the specified type was not found. The difference in indicators was statistically significant ( $p < 0.00001$ ). Type II was found in 28 (28.00%) patients and 68.29% (28/41) of joints with a neutral position of the lower limb axis. The indicated type was observed in 16 (42.11%) patients with morphotype II and 12 (41.38%) patients with morphotype III; the remaining groups did not have the indicated type of knee joint; the difference in indicators was significant ( $p=0.0003$ ). Type III was recorded in 14 (14.00%) patients and 58.33% (14/24) knee joints with valgus deviation of the lower limb axis, in particular in 5 (41.67%) individuals with morphotype IV, 8 (27.59%) patients with morphotype III, and 1 (2.63%) patient with morphotype II. This type was not observed in patients with morphotype I. When comparing frequency indicators in the formed groups, the difference was statistically significant ( $p=0.0002$ ).

**Table 2 – Characteristics of joint types according to the modified CPAK classification with regard to the morphotype of the knee joint**

Type	Variants of knee joint morphotypes				P
	I (n=21)	II (n=38)	III (n=29)	IV (n=12)	
I	21 (100.0%)	9 (23.68%)	0 (0.00 %)	0 (0.00 %)	<0.00001*
II	0 (0.00 %)	16 (42.11%)	12 (41.38%)	0 (0.00 %)	0.0003*
III	0 (0.00 %)	1 (2.63%)	8 (27.59%)	5 (41.67%)	0.0002*
IV	0 (0.00 %)	5 (13.16%)	0 (0.00 %)	0 (0.00 %)	0.04*
V	0 (0.00 %)	7 (18.42%)	6 (20.69%)	0 (0.00 %)	0.06
VI	0 (0.00 %)	0 (0.00 %)	2 (6.90%)	5 (41.67%)	<0.00001*
VII	0 (0.00 %)	0 (0.00 %)	0 (0.00 %)	0 (0.00 %)	1.00
VIII	0 (0.00 %)	0 (0.00 %)	0 (0.00 %)	0 (0.00 %)	1.00
IX	0 (0.00 %)	0 (0.00 %)	1 (3.44%)	2 (16.66%)	0.02*

Note: \* – difference in indicators was statistically significant at  $p \leq 0.05$

Type IV was found in 5 (5.00%) patients and 14.29% (5/35) of knee joints with a varus position of the lower limb axis. Type IV of the knee joint was recorded in 5 (13.16%) patients with morphotype II; in the remaining groups, this type was not observed; the difference was statistically significant ( $p=0.04$ ). Type V was observed in 13 (13.00%) individuals and 31.71% (13/41) of knee joints with a neutral position of the lower limb axis: 7 (18.42%) patients with morphotype II and 6 (20.69%) patients with morphotype III, and in none with morphotypes I and IV; the difference was not statistically significant ( $p=0.06$ ). Type VI was recorded in 7 (7.00%) patients and 29.17% (7/24) of valgus knee joints. The indicated type was found in 5 (41.67%) patients with morphotype IV and 2 (6.90%) patients with morphotype III; in those with morphotypes I and II, type VI of the knee joint was not observed; the difference in indicators was statistically significant ( $p < 0.00001$ ).

Type VII and type VIII were not reported in any case (0/35 and 0/41, respectively). Type IX was observed in 3 (3.00%) patients, which was 12.5% (3/24) of the knee joints with a valgus position of the lower limb axis. In particular, this type was found in 2 (16.66%) patients with morphotype IV and 1 (3.44%) patient with morphotype III; in the groups of patients with morphotypes I and II, type IX of the knee joint was not observed. The comparison demonstrated a statistically significant difference in frequency indicators in the formed groups ( $p=0.02$ ).

Evaluation of the prognostic value of mJLO and aHKA in determining the knee joint morphotype revealed that distal orientation of the knee joint line in patients with degenerative-dystrophic diseases is

associated with significantly lower chances of developing morphotype IV (OR=0.22, CI (0.06-0.79),  $p=0.02$ ) (Table 3). In contrast, proximal orientation of the knee joint line increases the chances of developing morphotype IV (OR=17.40, CI (1.40-216.10),  $p=0.02$ ).

Analysis of the calculated aHKA indicators confirmed that the aHKA values of  $\pm 2^\circ$ , indicating a neutral position of the lower limb axis, are associated with significantly higher chances of developing morphotypes II (OR=3.75, CI (1.58-8.87),  $p=0.002$ ) and III (OR=3.42, CI (1.37-8.49),  $p=0.006$ ). On the other hand, aHKA values of  $> 2^\circ$ , indicating a valgus position of the lower limb axis, significantly reduce the risk of developing morphotype II (OR=0.05, CI (0.006-0.37),  $p=0.00001$ ) and increase the risk of developing morphotype III (OR=2.73, CI (1.03-7.22),  $p=0.04$ ).

Additionally, we studied the possibility of predicting knee joint morphotypes in degenerative-dystrophic diseases based on the joint type according to the modified CPAK classification.

Significantly higher chances of developing morphotype II in patients with CPAK type II of the knee joint (OR=3.03, CI (1.22-7.54),  $p=0.01$ ) were confirmed (Table 4). CPAK type III is associated with significantly higher chances of developing morphotypes III (OR=4.13, CI (1.27-13.46),  $p=0.02$ ) and IV (OR=6.27, CI (1.62-24.32),  $p=0.01$ ) of the knee joint in degenerative-dystrophic processes and lower chances of developing morphotype II (OR=0.10, CI (0.01-0.84),  $p=0.005$ ). Significantly higher chances of developing morphotype IV were recorded in patients with CPAK types VI (OR=30.71, CI (4.90-192.34),  $p=0.00009$ ) and IX (OR=17.40, CI (1.40-216.10),  $p=0.02$ ).

**Table 3 – Prognostic value of mJLO and aHKA in determining knee joint morphotype**

	Variants of knee joint morphotypes			
	I	II	III	IV
mJLO				
<i>AD</i>	p=0.00007	p=0.53	p=0.67	p=0.02 OR=0.22 CI (0.06-0.79)
<i>AN</i>	p=0.0002	p=0.24	p=0.70	p=0.18
<i>AP</i>	p=0.23	p=0.09	p=0.87	p=0.02 OR=17.40 CI (1.40-216.10)
aHKA				
<-2°	p<0.00000001	p=0.76	p<0.00000001	p=0.0008
±2°	p=0.0000003	p=0.002 OR=3.75 CI (1.58-8.87)	p=0.006 OR=3.42 CI (1.37-8.49)	p=0.0002
>2°	p=0.0003	p=0.00001 OR=0.05 CI (0.006-0.37)	p=0.04 OR=2.73 CI (1.03-7.22)	p<0.00000001

**DISCUSSION**

The average mJLO in the patients was 174.28±5.20°, and the average aHKA was 0.19±4.74°, which indicated a predominantly distal orientation of the joint line and a neutral position of the lower limb axis in the patients of the study group. Our results are

consistent with the data of the study by Corban et al. (2024), where the average JLO in patients with knee osteoarthritis was 174.7±3.3°, and aHKA was (-0.1±4.0)°, as well as the study of Şenel et al. (2024), where the average values of JLO and aHKA were 174.6±3.7° and (-1.4±3.9)°, respectively [13, 14].

**Table 4 – Prognostic value of joint types according to the modified CPAK classification in determining the knee joint morphotype in gonarthrosis**

Type	Variants of knee joint morphotypes			
	I	II	III	IV
I	p<0.00000001	p=0.28	p=0.0000005	p=0.002
II	p=0.00007	p=0.01 OR=3.03 CI (1.22-7.54)	p=0.06	p=0.004
III	p=0.007	p=0.005 OR=0.10 CI (0.01-0.84)	p=0.02 OR=4.13 CI (1.27-13.46)	p=0.01 OR=6.27 CI (1.62-24.32)
IV	p=0.12	p=0.001	p=0.06	p=0.25
V	p=0.01	p=0.21	p=0.16	p=0.06
VI	p=0.06	p=0.008	p=0.98	p=0.00009 OR=30.71 CI (4.90-192.34)
IX	p=0.23	p=0.09	p=0.87	p=0.02 OR=17.40 CI (1.40-216.10)

The most common knee joint types according to the modified CPAK classification were types I (30.00%), II (28.00%), and III (14.00%). The data we obtained are a primary reflection of the prevalence of different knee joint types in the Ukrainian population. The established distribution is generally comparable to the results of the

studies by Şenel et al. (2024), Huber et al. (2023), and MacDessi et al. (2021), in which researchers noted a higher frequency of these types in patients with degenerative-dystrophic diseases of the knee joint [1, 8, 14]. Thus, in a large-scale study by Huber et al. (2023), which presents the results of the analysis of 8739

orthoradiographs of 7456 patients with knee joint osteoarthritis, CPAK type I was detected in 28.1% of subjects, type II – in 27.3% of subjects, and type III – in 20.9% of subjects [1]. The study by Şenel et al. (2024) presented the results of the evaluation of 408 knee osteoarthritis cases in 296 patients from the Turkish population. The most common CPAK types were type II (31.6%), type I (28.2%), and type III (13.5%) [14]. In the work of MacDessi et al. (2021) based on the analysis of radiological parameters of 500 knee joints affected by osteoarthritis, type I was found in 19.4% of cases, type II – in 32.2%, and type III – in 15.4% [8].

Most scientists noted the low prevalence of apical joint types of the knee joint – VII, VIII, and IX, which were recorded in 3.0% of the patients. The data we have established corresponds to global trends. Thus, the frequency of apical types according to Huber et al. (2023) was 1.3%; MacDessi et al. (2021) observed these types in 2.6% of cases; in the work of Mulpur et al. (2022), the frequency was 3.4% [1, 8, 15].

The high frequency of distal joint line orientation in patients with degenerative-dystrophic diseases of the knee joint is worth noting. The distal joint apex position was observed in the vast majority of patients examined – 72 (72.00%), which is consistent with the literature data. In particular, in the study by Şenel et al. (2024), the frequency of knee joint types with distal joint line orientation was 73.3%; in the paper of Huber et al. (2023), it was 76.3%; similar results were reported in the work of Corban et al. (2024) – 76.3% [1, 13, 14].

Despite the modification of the calculations, the results obtained are comparable with the data of world studies, which confirms the validity of the proposed approach to the CPAK-based analysis of knee joint morphotypes. In addition, our data provide further evidence of geographic variation in the distribution of knee joint morphotypes, as described in detail in the systematic review by Pagan et al. (2023). The researchers noted a significantly higher prevalence of varus forms of the knee joint, in particular CPAK type I, in Asian populations [2]. According to Toyooka et al. (2023), the frequency of CPAK type I in Japanese patients with knee osteoarthritis was 53.8%; in patients from India, this figure reached 58.8% [15, 16].

### CONCLUSIONS

As a result of the study, we confirmed the morphological variation of knee joints in degenerative-dystrophic diseases.

The average mJLO index in the examined patients was  $174.28 \pm 5.20^\circ$ , and the average aHKA angle was  $0.19 \pm 4.74^\circ$ , indicating a predominantly distal orientation of the joint line and a neutral position of the lower limb axis in patients with degenerative-dystrophic diseases of the knee joint. The most common knee joint types according to the modified CPAK classification were types I (30.00%), II (28.00%), and III (14.00%).

Thus, we believe that the high morphological variation of knee joints necessitates an individualized approach to planning orthopedic interventions for degenerative-dystrophic diseases.

### PROSPECTS FOR FUTURE RESEARCH

Studying the structural variation of the knee joint in degenerative-dystrophic diseases will allow us to improve the personalized approach to orthopedic interventions, particularly by determining the features of individualized positioning of endoprosthesis components.

### ETHICAL CONSIDERATIONS

The presented study was conducted in accordance with the ethical principles of the World Medical Association Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects (Seventh Revision, adopted at the 64th WMA General Assembly, Fortaleza, Brazil, October 2013), the Council of Europe Convention on Human Rights and Biomedicine (Oviedo, Spain, April 4, 1997), as well as in accordance with current national ethical standards. All participants were informed about their participation in the study and provided written informed consent. Patients' personal data were anonymized to ensure confidentiality.

### AUTHOR CONTRIBUTIONS

Kylymniuk L. O. – definition of the idea and concept of the research, statistical analysis of digital indicators, interpretation of the results obtained, writing the main text of the article; Matsipura M. M. – collection of clinical data and results of X-ray examination, critical review of the content of the manuscript, preparation of the list of used literature; Iaremyn S. Yu. – participation in the preparation of the manuscript text and analysis of the obtained results, performance of an analytical review of literary sources.

All authors agree to be responsible for all aspects of the research and to ensure the accuracy and scientific integrity of the publication.

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**CONFLICT OF INTEREST**

The authors have no conflict of interest to declare.

**ARTIFICIAL INTELLIGENCE DISCLOSURE**

The authors declare that no artificial intelligence-based technologies were used in writing or editing the manuscript.

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