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Peculiarities of degenerative changes in the proximal tibia according to knee joint morphotype

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Abstract. This study aimed to identify the characteristics of degenerative changes in the proximal tibia, taking into account the morphological variant of the knee joint. The analysis was based on radiographic examinations of 100 cases of gonarthrosis, predominantly affecting the medial compartment. The mean age of the patients was 63.56 ± 8.10 years. Among the radiographic criteria assessed were the anatomical medial proximal tibial angle (MPTA) and the femorotibial angle (FTA). In addition, morphometric parameters of the proximal tibia were evaluated relative to an axis drawn from the intercondylar eminence to the tibial condyles (LTCA, LTPA, MTPA, MTCA), as well as relative to an axis tangential to the condyles (LTCA2, LTPA2, MTPA2, MTCA2). The morphotypes of the knee joints were determined according to a proprietary cluster-based classification system. Statistical analysis was conducted using Statistica 13 software. Statistical significance was set at $p \leqslant 0.05$. Changes in LTCA and LTCA2 observed in patients with morphotypes I, II, and III indicated a medial deviation of the tibial axis. In patients with valgus deviation of the lower limb axis and knee joint morphotype IV, the decrease in LTCA and LTCA2 values indicated further destruction of the bone and cartilage tissues of the tibial condyle within the load-bearing area of the joint. It also reflected a shift of the axis tangential to the tibial condyles medially and downward, along with an upward deviation of the axis drawn from the intercondylar eminence to the lateral condyle. Changes in the LTPA, LTPA2, MTPA, and MTPA2 angles suggested a medial deviation of the tibia. An analysis of the MTCA and MTCA2 angles in patients with morphotypes II, III, and IV confirmed a medial shift of the tibia. Conversely, a decrease in MTCA and MTCA2 values in patients with morphotype I indicated further destruction of the bone and cartilage tissues of the medial condyle, as well as a downward and medial displacement of both the axis drawn from the intercondylar eminence to the medial condyle and the axis tangential to the condyles. These findings demonstrated a variation in the morphometric parameters of the proximal tibia depending on the identified knee joint morphotype in the context of degenerative-dystrophic conditions. The results may support the refinement of personalised approaches to orthopaedic interventions in degenerative dystrophic diseases of the knee joint

Keywords: osteoarthritis; degenerative-dystrophic diseases; morphology; radiographic parameters; gonarthrosis

INTRODUCTION

The study of anatomical variability in the proximal tibia, both under normal conditions and in the presence of degenerative-dystrophic diseases, is of significant relevance to orthopaedic practice. Assessing the shape of the tibia and the spatial relationships within the knee joint is essential for understanding the pathogenesis of degenerative-dystrophic diseases, identifying factors contributing to their progression, and selecting the most appropriate treatment method. An analysis of the morphological features of degenerative-dystrophic changes in the proximal tibia will support the development of individualised implants and enhance the personalised planning of surgical interventions such as proximal tibial osteotomy and total knee arthroplasty.

Degenerative-dystrophic joint diseases represent one of the most pressing challenges in modern orthopaedics due to their high prevalence and progressive nature. They are considered among the leading causes of chronic pain,

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functional limitations, and disability in the working-age population. Among all joints of the human musculoskeletal system, the knee is the most frequently affected by degenerativedystrophic changes [1-3]. Gonarthrosis is a comprehensive joint pathology characterised by structural alterations in the articular cartilage, subchondral bone, Hoffa's fat pad, synovial membrane, ligaments, and muscles [4, 5]. Therefore, the study of morphological changes in the knee joint under degenerative-dystrophic conditions has become a subject of considerable scientific interest.

In most cases, tissue degeneration begins in the medial compartment of the knee joint and, as the pathological process progresses, leads to disruption of the lower limb axis [6]. In the pathogenesis of gonarthrosis, particular attention should be paid to the condition of the proximal tibia, as its morphological changes determine the nature and severity of the resulting deformity. Understanding the anatomical variability and mechanisms of disease progression is key to improving existing treatment methods and developing more effective approaches for the management and prevention of gonarthrosis. The considerable variability of joint structures has been confirmed by the findings of A. Mullaji *et al*. [7], who, based on the analysis of 2,129 orthoradiographs, identified four phenotypic variations of knee osteoarthritis associated with varus alignment of the lower limb. The research group also demonstrated morphological variability in knee joints with valgus deviation.

In a separate study, A. Mullaji *et al*. [8] analysed orthoradiographs of 233 knee joints exhibiting valgus alignment and identified nine phenotypic variants of valgus knee osteoarthritis. Similarly, in a study by D. Yang *et al*. [9], five subtypes of valgus knee deformities were established based on the analysis of radiographs from 105 cases with valgus lower limb alignment. According to the researchers, the key factors contributing to the formation of distinct valgus knee morphologies include the pattern of local bone loss and deformation of the lateral tibial plateau, with or without valgus angulation at the level of the metaphysis.

Degenerative-dystrophic diseases of the knee joint affect not only the articular surface of the tibia but also cause significant deformation of the metaepiphyseal region. In a study by J. Tomczyk *et al*. [1], based on the analysis of computed tomography data from 23 patients with knee osteoarthritis and varus deformity, high variability was observed in the structural changes of the proximal epiphysis and metaepiphysis of the tibia. Using mathematical modelling, the researchers demonstrated significant differences in the three-dimensional dimensions of the tibial plateau, its inclination angle, and the medial and lateral tibial condyles, depending on body side and sex in patients with knee osteoarthritis and varus deformity. The study also confirmed a higher risk of varus osteoarthritis in the presence of deformation of the proximal tibial metaepiphysis.

Similar findings were reported by T. Ishibashi *et al*. [10], who used a three-dimensional (3D) model to demonstrate variations in the shape of the proximal tibia based on data from 31 patients with symptomatic knee osteoarthritis. The researchers found lower variability in the medial proximal cortical layer of the tibial metaphyseal region compared to the values for the tibial tuberosity area ($p = 0.004$) and the lateral cortex ($p = 0.020$). This was attributed to the greater load-bearing role of the medial compartment of the knee joint in cases of varus deviation of the lower limb axis. In contrast, the authors reported greater variability in the shape of the medial tibial plateau (1.46 mm) compared to the lateral plateau (1.16 mm) ($p = 0.044$), and noted less damage to the lateral compartment of the knee joint in patients with degenerative-dystrophic diseases. The researchers found that, as osteoarthritis progresses, cartilage destruction and bone erosion typically begin in the anteromedial area of the tibial plateau, with the pathological process subsequently extending posteriorly and laterally. However, it remains unclear whether changes in the proximal tibial metaepiphysis are a cause or a consequence of osteoarthritis.

This issue was addressed in a study by S. Kuriyama *et al*. [11], who used mathematical modelling of open wedge osteotomy with programmed values of the medial proximal tibial angle (MPTA) ranging from 90° to 97° in 1° increments. In all modelled scenarios, higher peak contact forces during walking were recorded in the lateral compartment of the knee joint compared to the medial one. The researchers demonstrated that an increase in MPTA is associated with excessive elevation of contact forces in the medial compartment and increased tension in the medial collateral ligament during knee flexion. The authors also observed non-physiological anterior rolling of the lateral femoral condyle during squatting, and the absence of the "screw-home" mechanism during knee extension in models with elevated MPTA values.

Morphological differences in the proximal tibia have been confirmed by the findings of J. Itou *et al*. [12]. Based on radiographic analysis of 109 knee joints, the authors identified three main types of tibial plateau shapes, according to the inclination of the medial and lateral articular surfaces. The majority of cases – 52 knees (47.71%) – exhibited a flat plateau (inclination up to 3°); a depressed shape was observed in 38 cases (34.86%), while a convex or "pagoda-shaped" form was identified in 19 knees (17.43%). The researchers highlighted the clinical relevance of analysing the morphology of the proximal tibia to improve outcomes of orthopaedic interventions for degenerative-dystrophic diseases of the knee joint.

Thus, most researchers share the view that a pronounced inclination of the tibial articular surface, as determined in the frontal plane, is associated with increased loading of the medial compartment of the knee joint, while the lateral compartment is subject to less stress. However, despite the available evidence, the influence of proximal tibial joint surface inclination on knee joint biomechanics remains insufficiently explored. This study aimed to characterise the morphological features of the proximal tibia in patients with degenerative-dystrophic diseases of the knee joint, according to knee joint morphotypes determined using a proprietary cluster-based classification system.

MATERIALS AND METHODS

This observational cross-sectional study analysed the radiographic findings of 100 cases of degenerativedystrophic knee joint disease, predominantly affecting the medial compartment, in 70 patients who received inpatient treatment at the Municipal non-commercial enterprise Vinnytsia City Clinical Emergency Hospital between 2017 and 2025. The mean age was 63.56 ± 8.10 years. The study group

included 26 men (37.14%) and 44 women (62.86%). Unilateral degenerative-dystrophic involvement of the knee joint was identified in 40 patients (57.14%), while a bilateral pattern was recorded in 30 cases (42.86%).

Inclusion criteria for the study were as follows: primary knee osteoarthritis (osteoarthritis), Kellgren-Lawrence grade II-III, with predominant medial compartment involvement; secondary knee osteoarthritis with medial compartment predominance, including cases following aseptic necrosis 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 apparatus; ability to fully extend the knee joint or presence of a flexion contracture of less than 10°. Exclusion criteria for the study included: total involvement of all compartments of the knee joint by the degenerative-dystrophic process; secondary post-traumatic osteoarthritis following a tibial plateau fracture; previous surgical interventions involving the proximal tibia (excluding arthroscopic meniscectomy); instability of the knee ligamentous apparatus; presence of a flexion contracture greater than 10°; secondary osteoarthritis caused by dysplastic bone changes, metabolic or other disorders (e.g. ochronosis, Gaucher's disease, Paget's disease, osteopetrosis); active infectious processes or latent infection.

The assessment of degenerative changes in the proximal tibia was carried out using standard (short) radiographs of the knee joints, taken in the anteroposterior projection under weight-bearing conditions. Among the radiographic criteria, the MPTA was evaluated. It was defined as the angle between a line tangential to the proximal articular surface of the tibia and the anatomical axis of the tibia, measured from the medial side [13]. The angle between the anatomical axes of the femur and tibia was defined as the femorotibial angle (FTA). In addition to standard parameters, morphometric measurements of the proximal tibia were taken concerning the axis drawn from the intercondylar eminence to the tibial condyles (Fig. 1), including:

- lateral tibial condylar angle (LTCA) – the angle between the line drawn from the intercondylar eminence to the lateral tibial condyle and the line tangential to the outer surface of the lateral tibial condyle;
- lateral tibial plateau angle (LTPA) – the angle between the line drawn from the intercondylar eminence to the lateral tibial condyle and a line parallel to the longitudinal axis of the tibia that intersects the horizontal axis at its central point;
- medial tibial plateau angle (MTPA) – the angle between the line drawn from the intercondylar eminence to the medial tibial condyle and a line parallel to the longitudinal axis of the tibia that intersects the horizontal axis at its central point;
- medial tibial condylar angle (MTCA) – the angle between the line drawn from the intercondylar eminence to the medial tibial condyle and the line tangential to the inner surface of the medial tibial condyle.

Morphometric parameters of the proximal tibia were also evaluated in relation to the axis tangential to the tibial condyles (Fig. 2):

- LTCA2 – the angle between the line drawn along the proximal articular surface of the tibia and the line tangential to the outer surface of the lateral tibial condyle;
- LTPA2 – the angle between the line drawn along the proximal articular surface of the tibia and a line parallel to the longitudinal axis of the tibia that intersects the horizontal axis at the midpoint between the intercondylar eminence and the outermost point of the lateral tibial condyle;
- MTPA2 – the angle between the line drawn along the proximal articular surface of the tibia and a line parallel to the longitudinal axis of the tibia that intersects the horizontal axis at the midpoint between the intercondylar eminence and the medial edge of the tibial condyle;
- MTCA2 – the angle between the line drawn along the proximal articular surface of the tibia and the line tangential to the inner surface of the medial tibial condyle.

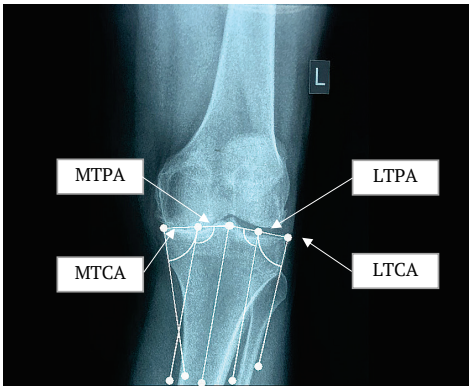


Figure 1. Anteroposterior radiograph of the left knee joint of patient M., aged 49
Note: diagnosis – primary osteoarthritis of the left knee, grade III, predominantly affecting the medial compartment. Knee joint morphotype – type II. LTCA – 88.6°; LTPA – 91.9°; MTPA – 102.6°; MTCA – 83.9°
Source: author's photo

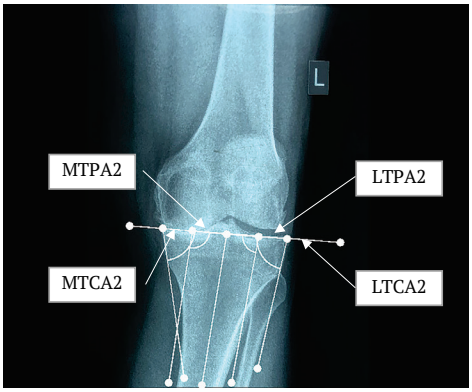


Figure 2. Anteroposterior radiograph of the left knee joint of patient M., aged 49
Note: diagnosis – primary osteoarthritis of the left knee, grade III, predominantly affecting the medial compartment. Knee joint morphotype – type II. LTCA2 – 81.6°; LTPA2 – 83.6°; MTPA2 – 93.0°; MTCA2 – 76.6°
Source: author's photo

The morphotypes of knee joints affected by the degenerative-dystrophic process were determined using a proprietary cluster classification system [14]. The study

was conducted in accordance with the ethical principles of the Declaration of Helsinki by the World Medical Association [15], the Convention on Human Rights and Biomedicine [16], as well as the applicable national ethical standards of Ukraine [17]. All participants were informed about their involvement in the study and provided written informed consent. To ensure confidentiality, all personal data of the patients examined were anonymised.

Statistical analysis of the numerical data was performed using the software package Statistica 13. Descriptive statistical methods were used to evaluate and analyse quantitative data. Continuous variables are presented as mean ± standard deviation (M ± SD), while categorical variables are expressed as absolute numbers of observations (n) and corresponding percentages (%). For comparisons between independent groups, the non-parametric Kruskal-Wallis test was applied. The functional relationship between variables was assessed using Kendall's tau (τ) rank correlation coefficient. The predictive value of the analysed parameters for determining the morphotype of the knee joint affected by degenerativedystrophic changes was evaluated using a binary logistic regression model, with odds ratios (OR) and 95% confidence intervals (CI) calculated. Statistical significance for predictive accuracy was set at $p \leqslant 0.05$.

RESULTS AND DISCUSSION

According to the proprietary cluster classification system [14], four groups were identified among the examined patients, corresponding to four morphological variants of knee joint structure in the context of degenerative-dystrophic disease. Morphotype I was identified in 21 patients (21.00%), morphotype II in 38 (38.00%), morphotype III in 29 (29.00%), and morphotype IV in 12 (12.00%). The mean FTA among all patients was 177.09° ± 5.57°. In patients with morphotype I, the mean FTA was 169.76° ± 1.48°, indicating varus deviation of the lower limb axis. Varus deviation of the limb axis was also observed in patients with morphotype II, whose mean FTA was 175.58° ± 1.32°. In patients with morphotype III, the mean FTA was 180.14° ± 1.49°, corresponding to a neutral lower limb alignment. Among individuals with morphotype IV, the mean value of the measured angle was 187.33° ± 3.75°, indicating valgus deviation of the axis. A comparison of the mean FTA values across the groups revealed a statistically significant difference ($p < 0.0001$).

Assessment of the morphometric parameters of the proximal tibia relative to the axis extending from the intercondylar eminence to the tibial condyles showed that the mean LTCA among all participants was 89.31° ± 7.09°. The lowest angle values were recorded in individuals with morphotype I – 86.12° ± 7.11°; in patients with morphotype II, the mean LTCA was 88.87° ± 6.09°; in those with morphotype IV – 88.17° ± 7.08°; and the highest values were observed in individuals with morphotype III – 92.67° ± 7.26°. The differences between these values were statistically significant ($p = 0.02$) (Table 1). No significant correlation was found between LTCA and FTA values ($\tau = +0.13$, $p = 0.05$).

Table 1. Characteristics of morphometric parameters of the proximal tibia relative to the axis drawn from the intercondylar eminence to the tibial condyles

	Variants of knee joint morphotypes				p
	I (n = 21)	II (n = 38)	III (n = 29)	IV (n = 12)	
LTCA	86.12 ± 7.11°	88.87 ± 6.09°	92.67 ± 7.26°	88.17 ± 7.08°	0.02*
LTPA	89.57 ± 5.47°	93.50 ± 3.79°	95.52 ± 2.97°	99.83 ± 4.97°	<0.00001*
MTPA	105.67 ± 6.69°	101.79 ± 10.07°	99.90 ± 7.22°	98.83 ± 4.59°	<0.00001*
MTCA	77.74 ± 6.14°	83.32 ± 6.33°	80.31 ± 6.67°	79.17 ± 4.43°	0.02*

Note: * – statistically significant difference at $p \leqslant 0.05$
Source: developed by the author

Analysis of the LTPA values demonstrated a statistically significant difference depending on the morphological characteristics of the knee joint structure in degenerative-dystrophic conditions ($p < 0.00001$). The highest LTPA values were observed in individuals with morphotype IV – 99.83° ± 4.97°, followed by patients with morphotype III – 95.52° ± 2.97°, morphotype II – 93.50° ± 3.79°, and morphotype I – 89.57° ± 5.47°. The overall mean LTPA among patients was 94.02° ± 5.07°. Moreover, higher LTPA values were significantly associated with higher FTA values, as confirmed by a direct correlation between the indicators ($\tau = +0.36$, $p < 0.0000001$).

The mean value of the MTPA among the participants was 101.7° ± 8.33°. The highest MTPA values were observed in patients with morphotype I – 105.67° ± 6.69°, followed by morphotype II – 101.79° ± 10.07°, morphotype III – 99.90° ± 7.22°, and morphotype IV – 98.83° ± 4.59°. Comparison of MTPA values based on the morphological structure of the knee joint confirmed a statistically significant difference ($p < 0.00001$). It was established that higher MTPA values are associated with varus alignment of the lower limb axis and correspondingly lower FTA values ($\tau = -0.37$, $p < 0.0000001$). The mean value of the MTCA was 80.78° ± 6.49°. Among individuals with morphotype I, the mean value of the MTCA was 77.74° ± 6.14°, in patients with morphotype II – 83.32° ± 6.33°, in those with morphotype III – 80.31° ± 6.67°, and in morphotype IV – 79.17° ± 4.43°. These differences were statistically significant ($p = 0.02$). No significant correlation was found between MTCA and FTA values ($\tau = -0.008$, $p = 0.91$).

Analysis of the morphometric parameters of the proximal tibia relative to the axis tangential to the femoral condyles revealed that the mean value of the LTCA2 was 80.78° ± 6.69°. The lowest values were observed in patients with morphotype I – 77.60° ± 6.59°, while in morphotype II the mean was 80.17° ± 7.61°, in morphotype III – 83.03° ± 4.04°, and morphotype IV – 82.83° ± 7.04°. The differences were statistically significant ($p = 0.008$) (Table 2). Furthermore,

higher LTCA2 values were found in patients with valgus alignment of the lower limb axis and correspondingly higher FTA values, which were confirmed by a direct correlation between the two indicators ($\tau = +0.23$, $p = 0.0009$).

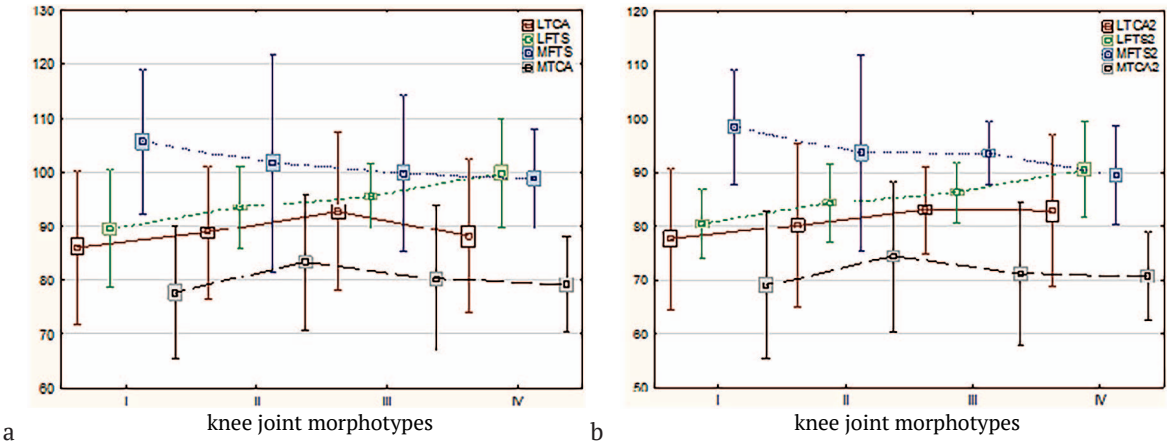
Table 2. Characteristics of morphometric parameters of the proximal tibia relative to the axis tangential to the femoral condyles

	Variants of knee joint morphotypes				p
	I (n = 21)	II (n = 38)	III (n = 29)	IV (n = 12)	
LTCA2	77.60 ± 6.59°	80.17 ± 7.61°	83.03 ± 4.04°	82.83 ± 7.04°	0.008*
LTPA2	80.43 ± 3.23°	84.37 ± 3.65°	86.29 ± 2.78°	90.46 ± 4.43°	< 0.00001*
MTPA2	98.36 ± 5.34°	93.68 ± 9.08°	93.53 ± 2.89°	89.5 ± 4.59°	< 0.00001*
MTCA2	69.05 ± 6.82°	74.39 ± 6.96°	71.14 ± 6.64°	70.67 ± 4.06°	0.03*

Note: * – statistically significant difference at $p \leq 0.05$
Source: developed by the author

A highly significant difference in LTPA2 values across the groups was confirmed ($p < 0.00001$). The overall mean LTPA2 was 84.83° ± 4.49°. The highest values were observed in individuals with valgus deviation of the lower limb axis – 90.46° ± 4.43°, followed by patients with morphotype III – 86.29° ± 2.78°, morphotype II – 84.37° ± 3.65°, and the lowest in morphotype I – 80.43° ± 3.23°. A moderate direct correlation was identified between the LTPA2 and FTA values ($\tau = +0.53$, $p < 0.0000001$). The mean value of the MTPA2 among the participants was 94.12° ± 6.92°. The highest MTPA2 values were recorded in individuals with morphotype I – 98.36° ± 5.34°, followed by morphotype II – 93.68° ± 9.08°, morphotype III – 93.53° ± 2.89°, and morphotype IV – 89.5° ± 4.59°. These differences were statistically significant ($p < 0.00001$). It was demonstrated that higher MTPA2 values are associated with lower FTA values, confirmed by a negative correlation between the two indicators ($\tau = -0.45$, $p < 0.0000001$).

Analysis of MTCA2 values across the groups confirmed a statistically significant difference depending on the morphological characteristics of the knee joint structure ($p = 0.03$). The mean MTCA2 value in patients with morphotype I was 69.05° ± 6.82°, in morphotype II – 74.39° ± 6.96°, in morphotype III – 71.14° ± 6.64°, and in morphotype IV – 70.67° ± 4.06°. The overall mean value of this angle was 71.88° ± 6.80°. No statistically significant correlation was found between MTCA2 and FTA values ($\tau = -0.01$, $p = 0.87$). The differences in morphometric parameters of the proximal tibia, as measured relative to the axis drawn from the intercondylar eminence to the condyles, and relative to the tangent to the tibial condyles, are illustrated in Figure 3.



a b

Figure 3. Box plot of morphometric parameters of the proximal tibia
Note: a – relative to the axis drawn from the intercondylar eminence to the condyles; b – relative to the tangent to the tibial condyles
Source: developed by the author

Based on the obtained data, it was established that changes in the morphological configuration of the medial condyle of the tibia played a key role in the development of lower limb axis deviation. Significant destruction of the medial tibial compartment in cases of pronounced varus deformity was reported in the study by E.B. Demir *et al*. [18]. The researchers found that patients with HKA angle values greater than 20.6° had approximately a sixfold increased risk of requiring medial augmentation during total knee arthroplasty. In the study by H. Nilsson *et al*. [19], a higher risk of developing medial compartment osteoarthritis of the knee was observed in patients with more severe varus deformity and correspondingly lower HKA angle values. Deformation of the medial femoral condyle in the presence of varus alignment of the lower limb axis was also confirmed by the findings of Z. Zhang *et al*. [20]. The authors noted that correction of varus deviation through osteotomy and restoration of optimal mechanical MPTA and

FTA values leads to a reduction in cartilage loading and a shift in stress from the medial to the lateral compartment of the joint. This, in turn, promotes redistribution of the centre of gravity in the frontal plane.

Further support for this conclusion is provided by the study of H. Zhang *et al*. [21], who used computer modelling to develop three-dimensional simulation models of knee osteoarthritis with varying degrees of varus deformity (0°, 3°, 6°, 9°, 12°, 15°, 18°). They analysed the distribution of Von-Mises stress and peak stress values for the cartilage of the femoral condyles and the medial and lateral tibial plateaus. The researchers observed a marked increase in axial load on the lower limb in the medial direction, as well as elevated peak stress values in the medial compartment of the knee joint, corresponding with the degree of varus deviation of the lower limb axis. They identified higher levels of loading on the medial cartilage and a greater frequency of damage in areas of peak stress when the varus deviation exceeded 6°.

In an analysis of 1,158 computed tomography scans of knee joints from 193 patients with osteoarthritis and 965 healthy individuals, A. Siddiqi *et al*. [22] found significant differences in several morphometric parameters. These included the posterior condylar axis (0.3° ± 1.5° versus 1.2° ± 1.9°, respectively), the medial-to-lateral posterior condylar offset ratio (1.01 ± 0.06 versus 1.04 ± 0.07, respectively), the medial-to-lateral condylar radius ratio (0.98 ± 0.07 versus 1.03 ± 0.07, respectively), and the tibial slope in both sagittal and frontal planes. Specifically, medial posterior plateau slope was 8.4° ± 4.0° versus 9.2° ± 4.0°, lateral posterior plateau slope was 9.2° ± 3.6° versus 7.2° ± 3.3°, and medial frontal tilt was 82.1° ± 4.3° versus 83.9° ± 3.3°, respectively.

Distinct findings were reported in the study by S.H. Alruwaili *et al*. [23], who assessed differences in the orientation of the joint lines of the medial and lateral tibial plateaus about the horizontal line of the mechanical axis of the tibia (TPD, tibial plateau difference) in 181 women with degenerative-dystrophic knee joint conditions (181 knee joints). The researchers did not identify any statistically significant differences in TPD values ($p = 0.662$), the levels of the medial and lateral femoral condyles ($p = 0.54$), MPTA ($p = 0.169$), or the posterior slope of the tibial plateau ($p = 0.466$) between groups stratified by the severity of osteoarthritis. However, the authors noted a statistically significant correlation between increased TPD and greater mechanical FTA ($p < 0.01$).

The morphological characteristics of the lateral compartment of the knee joint in gonarthrosis, particularly in relation to the alignment of the lower limb axis, remain insufficiently studied. In the study by W. Ma *et al*. [24], the authors observed lateral displacement of the tibial plateau, curvature of the proximal fibula, and elevation of the fibular head in cases of knee osteoarthritis accompanied by varus deviation of the lower limb axis. In a retrospective study by Z. Wang *et al*. [25], based on analysis of radiographs from 414 patients (789 knee joints), the researchers concluded that varus deformity of the proximal tibia was linked to the morphological features of the epiphyseal and metaepiphyseal regions. Among women, progressive and asymmetrical subsidence of the tibial epiphysis was observed with age, which, according to the authors, contributed to the development of dynamic varus deformity of the proximal tibia. In a separate study, M. Kulynych & Yu. Mochalov [26] found that the degree of midface deformity in children with congenital defects of the alveolar process of the maxilla was directly proportional to the size of the defect. The anthropometric parameters of the nasolabial complex prior to surgery are critically important for selecting the appropriate surgical approach and type of bone graft.

The findings of the present study are broadly consistent with existing literature and confirm the morphological variability of degenerative-dystrophic changes in the proximal tibia across different knee joint morphotypes. Moreover, the results highlight the complex and multifactorial relationship between the morphometric characteristics of the proximal tibia and the alignment of the lower limb axis. The identified morphometric differences support the rationale for differentiating knee joint morphotypes in degenerative-dystrophic conditions and underscore the need to individualise orthopaedic treatment planning. This is particularly relevant for corrective osteotomy, unicondylar, and total knee arthroplasty.

CONCLUSIONS

The study established differences in degenerative changes in the proximal tibia depending on the morphotype of the knee joint, as classified using a proprietary clustering system. In groups categorised according to the morphological variant of the knee joint, statistically significant differences were identified in the structural and spatial characteristics of the proximal tibia. These included angular values measured relative to an axis drawn from the intercondylar eminence to the tibial condyles – namely, LTCA ($p = 0.02$), LTPA ($p < 0.00001$), MTPA ($p < 0.00001$), and MTCA ($p = 0.02$) – as well as parameters measured relative to an axis tangential to the condyles – LTCA2 ($p = 0.008$), LTPA2 ($p < 0.00001$), MTPA2 ($p < 0.00001$), and MTCA2 ($p = 0.03$). Changes in the morphology of the proximal tibia depending on the alignment of the lower limb axis were confirmed by significant correlations between FTA values and LTPA ($\tau = +0.36$, $p < 0.0000001$), MTPA ($\tau = -0.37$, $p < 0.0000001$), LTCA2 ($\tau = +0.23$, $p = 0.0009$), LTPA2 ($\tau = +0.53$, $p < 0.0000001$), and MTPA2 ($\tau = -0.45$, $p < 0.0000001$). The absence of significant correlations between FTA and LTCA ($\tau = +0.13$, $p = 0.05$), MTCA ($\tau = -0.008$, $p = 0.91$), and MTCA2 ($\tau = -0.01$, $p = 0.87$) indicates the complexity and multifactorial nature of the spatial relationships among the components of the deformity. It has been demonstrated that degenerative-dystrophic changes in the proximal tibia in individuals with knee joint morphotypes II and III are primarily associated with medial deviation of the longitudinal tibial axis. In contrast, in morphotypes I and IV, such changes are largely attributable to additional destruction of the cartilage and bone tissues of the medial femoral condyle. These findings confirm the appropriateness of a personalised approach when planning orthopaedic interventions for patients with degenerative-dystrophic knee joint disorders. Taking into account the specific morphological variant of the knee joint allows for more accurate prediction of pathological progression mechanisms and provides a rationale for selecting the most suitable surgical strategy. A promising direction for further research is the analysis of morphological features of the distal femur in degenerative-dystrophic knee conditions, with consideration of the identified morphological variant. Equally important is the assessment of structural changes within the knee joint occurring in the sagittal and

axial planes to enable a comprehensive understanding of joint biomechanics in three-dimensional space.

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Особливості дегенеративних змін проксимального відділу великогомілкової кістки залежно від морфотипу колінного суглоба

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Анотація. Мета роботи полягала у визначенні особливостей дегенеративного ураження проксимального відділу великогомілкової кістки, враховуючи морфологічний варіант колінного суглоба. Проаналізовано результати рентгенографічного обстеження 100 випадків гонартрозу з переважним ураженням медіального відділу. Середній вік – 63,56 ± 8,10 років. Серед рентгенологічних критеріїв оцінювались анатомічний медіальний проксимальний великогомілковий кут (MPTA) та стегново-гомілковий кут (FTA). Додатково оцінювались морфометричні показники проксимального відділу великогомілкової кістки відносно осі, проведеної від міжвиросткового підвищення до виростків великогомілкової кістки (LTCA, LTPA, MTPA, MTCA) та відносно осі, дотичної до виростків (LTCA2, LTPA2, MTPA2, MTCA2). Морфотип колінних суглобів було встановлено відповідно до власної кластерної системи. Статистичний аналіз було виконано з використанням програмного засобу Statistica 13. Рівень статистичної значущості визначено при $p \leqslant 0,05$. Встановлені зміни показників LTCA та LTCA2 у пацієнтів з морфотипом I, II, III свідчили про відхилення осі великогомілкової кістки досередини. У пацієнтів з вальгусним відхиленням осі нижньої кінцівки та морфотипом колінного суглоба IV зниження показників кутів LTCA та LTCA2 вказувало на додаткове руйнування кісткової та хрящової тканин виростка великогомілкової кістки опорної зони суглоба та зміщення осі, дотичної до виростків великогомілкової кістки, досередини і донизу та відхилення осі, проведеної від міжвиросткового підвищення до латерального виростка, догори. Зміни кутів LTPA, LTPA2, MTPA та MTPA2 свідчили про відхилення великогомілкової кістки досередини. Аналізуючи значення кутів MTCA та MTCA2 у пацієнтів з морфотипом II, III та IV, встановлено відхилення великогомілкової кістки досередини. Натомість, зменшення значення кутів MTCA та MTCA2 у пацієнтів з морфотипом I свідчило про додаткове руйнування кісткової та хрящової тканин медіального виростка та зміщення як осі, проведеної від міжвиросткового підвищення до медіального виростка, так і осі, дотичної до виростків, донизу та досередини. Таким чином, доведено відмінність морфометричних показників проксимального відділу великогомілкової кістки залежно від встановленого морфотипу колінного суглоба при дегенеративно-дистрофічних захворюваннях. Отримані дані дозволять удосконалити персоніфікований підхід до ортопедичного втручання при дегенеративно-дистрофічних захворюваннях колінного суглоба

Ключові слова: остеоартроз; дегенеративно-дистрофічні захворювання; морфологія; рентгенологічні параметри; гонартроз