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ORIGINAL ARTICLE

MORPHOMETRIC PARAMETERS OF THE DISTAL END OF THE FEMUR AND THEIR INFLUENCE ON THE KNEE JOINT

MORFOMETRIJSKI PARAMETRI DISTALNOG OKRAJKA BUTNE KOSTI I NJIHOV UTICAJ NA ZGLOB KOLENA

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Abstract

Introduction: The femur is a long pair of bones and it consists of the proximal, distal end and body. The distal end carries the medial and lateral condyle (*condylus medialis et lateralis*), the intercondylar fossa and line (*linea et fossa intercondylaris*), and together with the patella (*patella*) and tibia (*tibia*) forms the knee joint. This study considers the effects of certain parameters on the femurs on the knee joint, and in addition to the fact that anthropometrically important parameters also represent important clinical indications during operations on the knee joint, that can become necessary due to the consequences of various diseases or environmental factors.
Aim: Study of morphometric parameters of the distal end of the femur which are of exceptional importance in orthopedic surgery of the hip joint when planning osteocorrective interventions.
Material and methods: At the Institute for Anatomy "Niko Miljanić" in Belgrade in 2020, a number of 47 femurs were measured, out of which 22 were right and 25 were left. Shaft length, lateral distal femoral angle (LDFA), mechanical lateral distal femoral angle (mLDFA) were measured, and for all measurements an orthopedic digital goniometer accurate to two decimal places was used.
Results: A total of 47 femurs with an average shaft length of 40.0 ± 2.69 were processed. The shortest specimen was 34.8 cm while the longest was 45.7 cm. The mean LDFA was 81.36 ± 2.95 degrees, the minimum was 81.8 degrees while the maximum was 89.9 degrees. The average mLDFA was 87.69 ± 2.99 degrees, while the maximum and minimum were 94.6 and 81.8 degrees, respectively.
Conclusion: Thirteen measured femurs fell under the definition of either *genu varum* or *genu valgum*. Four right and three left femurs are defined as *varum*, while two right and four left are defined as *valgum*. Additional analysis is necessary to determine the clinical implications of these parameters.

Keywords:
femur,
knee,
knee joint,
genu varum,
genu valgum

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Sažetak

Uvod: Butna kost (*femur*) je duga parna kost koja čini kostur buta. Ona se sastoji iz proksimalnog, distalnog okrajka i tela. Distalni okrajak na sebi nosi unutrašnji i spoljašnji kondil (*condylus medialis et lateralis*), međukondilarnu jamu i liniju (*linea et fossa intercondylaris*), i zajedno sa čašicom (*patella*) i golenjačom (*tibia*) formira zglob kolena. Ovom studijom su razmatrani uticaji određenih parametara, prisutnih na butnim kostima, na zglob kolena. I pored činjenice da su parametri bitni antropometrijski, oni predstavljaju i bitne kliničke činioce prilikom operacija na zglobu kolena, koje postaju neophodne kao posledica raznovrsnih patologija, npr. tipa IV mukopolisaharidoze ili faktora spoljašnje sredine, npr. endemske fluoroze.

Cilj: Cilj rada je proučavanje i analiza morfometrijskih parametara distalnog okrajka femura iz osteološke zbirke Instituta za anatomiju „Niko Miljanić", koje su od izuzetnog značaja u ortopedskoj hirurgiji zgloba kolena pri planiranju osteokorektivnih intervencija, kao i u cilju utvrđivanja učestalosti angularnih poremećaja zgloba kolena.

Materijal i metode: Na Institutu za anatomiju "Niko Miljanić" u Beogradu 2020. godine korišćeno je i izmereno 47 butnih kostiju, od kojih su 22 desne, a 25 je levih. Izmerena je dužina osovine (*Shaft*), lateralni distalni femoralni ugao (engl. *Lateral distal femoral angle,* LDFA), mehanički lateralni distalni femoralni ugao (engl. *Mechanical lateral distal femoral angle,* mLDFA) i za sva je korišćen ortopedski digitalni goniometar precizan na dve decimale.

Rezultati: Obrađeno je ukupno 47 butnih kostiju sa prosečnom dužinom osovine 40,0 ± 2,69 cm. Najkraći primerak je iznosio 34,8 cm dok je najduži bio 45,7 cm. Prosečni LDFA je iznosio 81,36 ± 2,95 stepeni, minimalni je iznosio 81,8 stepeni, dok je maksimalni bio 89,9 stepeni. Prosečan mLDFA je iznosio 87,69 ± 2,99 stepeni, dok su maksimalni i minimalni bili 94,6 i 81,8 stepeni..

Zaključak: Trinaest izmerenih butnih kostiju je potpadalo pod definiciju ili *genu varum* ili *genu valgum*. Od njih se četiri desna i tri leva femura definišu kao *varum*, dok se dva desna i četiri leva definišu kao *valgum*. Neophodna je dodatna analiza za utvrđivanje kliničkih implikacija ovih parametara.

Ključne reči:
femur,
zglob kolena,
genu varum,
genu valgum

Introduction

The femur is the longest axial pair of bones in the thigh and extends from the hips to the knees (1). Like any long bone, the femur has a body (*corpus*) and a proximal and distal end. The proximal end carries the large trochanter, the small trochanter (*trochanter major, trochanter minor*), the head (*caput*) and the neck (*collum*) of the femur. The head also represents the articular surface of the hip joint, which is articulated with the acetabulum on the pelvic bone. Along the back of the body of the femur, a rough line (*linea aspera*) extends, which makes a trifurcation at the proximal end, and a bifurcation at the distal end .

The distal extremity is larger than the proximal extremity and has a somewhat cuboidal shape. Two ovoid structures can be seen on it, medial and lateral condyles (*condylus medialis et lateralis*) above which are medial and lateral epicondyles (*epicondylus medialis et lateralis*). Between the condyles, on the posterior side, a depression called the intercondylar pit (*fossa intercondilaris*) is formed, which is limited on both sides by the condyles themselves, while on its upper side it is limited by the intercondylar line (*linea intercondilaris*). This line represents the line drawn between the highest points of both condyles. On the anterior side of the distal end is the articular surface for the patella (*facies patellaris*).

The condyles, together with the cup (*patella*) and the upper end of the tibia, form the knee joint (*art. genu*), which carries most of the body weight, together with the hip joint (*art. coxae*). The knee joint is the largest hinged joint (*ginglymus*) in the human body, which is stabilized by numerous ligaments and muscles. The distal extremity bears the lateral distal femoral angle, the mechanical lateral distal femoral angle, and the Mechanical Anatomical Angle, which will be described in more detail later in the materials and methods. These angles represent morphometric parameters that are of great practical importance when planning osteocorrective interventions on the knee joint, and can often be a direct cause of *genu varum* et *genu valgum,* which represent deformities of the knee joint in the coronary plane (2). Such disorders often occur physiologically in children, but are also often resolved without surgical intervention (4).

The diagnosis of the *valgum* and *varum* genes is established by measuring the angle between the anatomical and mechanical axis of the femur (hereinafter referred to as "Mechanical Anatomical Angle" - "MAA") (5). Normal MAA is defined in the range of 5-7 degrees with normal standard deviations depending on ethnicity, age, gender and body mass index. This reference value was chosen as the most cited reference value in scientific journals and papers; however, itis not considered to be of great importance for this paper due to the lack of an appropriate tibia to support the diagnosis of *genu valgum* or *varum*.

Nevertheless, this paper will extract all femurs that would fall into this definition of angular knee deformities, guided only by MAA as a reference value, but will not explicitly diagnose *genu varum* or *valgum* (5). This data is of clinical importance for various surgical procedures such as complete knee arthroplasty. The aim of this research is to study and analyze the morphometric parameters of the distal end of the femur from the osteological collection of the Institute of Anatomy "Niko Miljanić", which are extremely important in orthopedic hip surgery when planning osteocorrective interventions, as well as to determine the frequency of angular knee disorders.

Materials and methods

During this descriptive study, forty-seven femurs from the archives of the osteological collection of the Institute of Anatomy "Niko Miljanic" of the Faculty of Medicine University of Belgrade were used, out of which twenty-five were right and twenty-two left, without the information regarding age and gender of the cadavers (**Figure 1A and B**).

Figure 1A. Photograph of all used femur samples of right orientation from the osteological archive of the Institute of Anatomy "Niko Miljanic" of the Faculty of Medicine University of Belgrade

Figure 1B. Photograph of all used femur samples of left orientation from the osteological archive of the Institute of Anatomy "Niko Miljanic" of the Faculty of Medicine University of Belgrade

Four parameters were measured with the intent to determine the significance of their values in the genesis of pathologies and changes in the knee joint:

- Axis length - which represents the line drawn between the middle of the intercondylar line (*linea intercondilaris*), i.e. the upper border of the intercondylar fossa (*fossa intercondilaris*) and the highest point of the large trochanter of the proximal end (*trochanter major*). This parameter played a role in considering the influence of sample height with the development of angular knee deformities;
- Lateral distal femoral angle (hereinafter "LDFA") - the angle between the axis of the femur and the line drawn through the lowest point of both condyles that is parallel to the ground. There is a distinct ramification in certain authors when discussing the range of LDFA reference values. In this paper, the reference value of 79-83 degrees was used as the most cited reference value in orthopedic papers and journals (6);
- Mechanical lateral distal femoral angle (hereinafter "mLDFA") - the angle between the mechanical axis of the femur and the line drawn through the lowest point of both condyles parallel to the ground. The mechanical axis is defined as the line drawn between the center of the femoral head (*caput femoris*) and the middle of the intercondylar line (*linea intercondilaris*). There are different mLDFA reference values from different authors. In this paper, the reference value of 85-90 degrees was used, as the most cited in scientific journals and papers (7) (**Figure 2**);
- The angle situated between the mechanical and anatomical axis of the femur (hereinafter mechanical anatomical angle – „MAA").

A digital orthopedic goniometer (Iskra 5422-200) accurate to two decimal places was used for measurements. For statistical analysis, the program SPSS v25.0 was used. Student's t-test and Pearsons linear correlation coefficient methods were used for statistical comparison

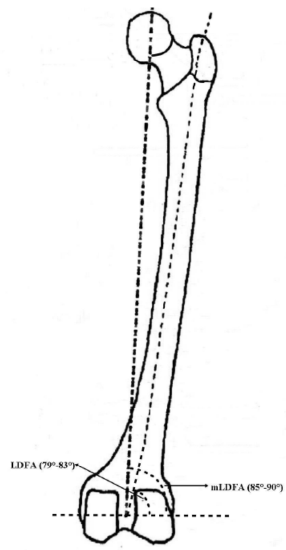


Figure 2. Angles of distal end of femur

of left and right femurs and for the correlation table, respectively.

Femurs of left and right orientation were also determined, as well as the difference in values of aforementioned parameters, which will be described in more detail in the discussion.

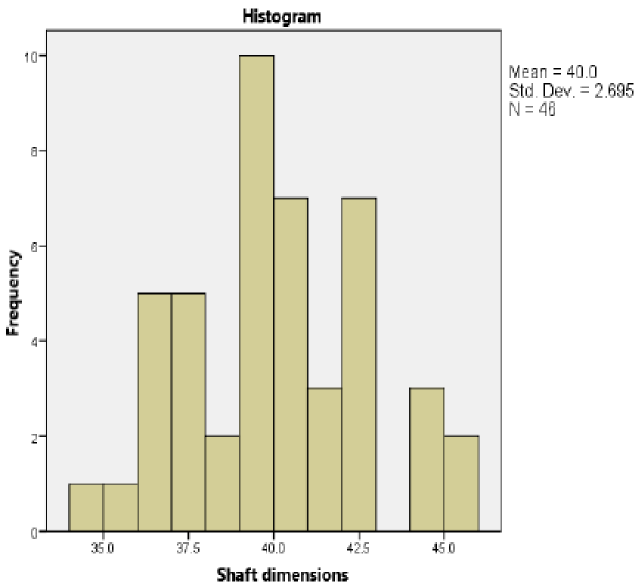
Results

The length of the femoral axis varied from 35.5 cm to 44.9 cm, while the average was 40.7 cm (**Graph 1**).

No statistically significant difference was found between the femoral axis length in femurs with left and right orientation (p = 0.110). In the left femur, the LDFA was below reference values in three cases, and above reference values in six cases. On the other hand, the LDFA of the right femur was above reference values on three occasions, and below reference values in five cases. The results varied from 76.8° which was the lowest value, to 89.9° as the highest, with an average of 82.14°. In the left femur, the mLDFA was above reference values eight times, while it was below only three times. The right femurswere found to be above the reference values three times, after mLDFA measurements, and below the reference values six times.

The lowest value was 84.3° while the highest was 94.6°, with an average of 88.44°. Their LDFA was also measured, and it was determined that it averaged 81.36 ± 2.95°, of which the extremes were 73° and 85.3°. The averaged mLDFA was 87.69 ± 2.99°, while the maximum value was 91.9°, the minimum 81.8 °. Twenty-five samples (53.2%) had a left orientation, while twenty-two samples (46.8%) had a right orientation. There is a relationship between LDFA and mLDFA of left and right orientation, with LDFA of right orientation being statistically smaller than mLDFA of left orientation (p = 0.052).

No statistically significant difference was found between the length of the left and right orientation axis (p = 0.110), nor between mLDFA left and right orientation (p = 0.260), which was important to determine the difference in this angle in people with left and right dominant leg (**Table 1**). A significant relationship was found between LDFA and mLDFA (p <0.001) (**Table 2**).



Graph 1. Histogram of frequency according to the length of the femur axis (X axis = Shaft dimensions; Y axis = Frequency)

Table 1. Average values of axis, LDFA and mLDFA based on left and right orientation

Variable	Left orientation	Right orientation	p-value (Pearson correlation)
Femoral axis length	39,41±2,60	40,70±2,70	0.110
LDFA	82,14±2,84	80,47±2,87	0.052
mLDFA	88,15±2,98	87,16±2,98	0.260

Table 2. Value correlations

		Axis dimensions	LDFA	mLDFA
Axis dimensions	Pearson correlation		.102	.117
	Sig. (2-tailed)		.502	.438
	N		46	46
LDFA	Pearson correlation	.102		.707**
	Sig. (2-tailed)	.502		.000
	N	46		47
mLDFA	Pearson correlation	.117	.707**	
	Sig. (2-tailed)	.438	.000	
	N	46	47	

**Correlation is significant at the 0.01 level (2-tailed)

Discussion

Angular deformities of the knee disrupt the biomechanics of the entire joint and lead to an uneven distribution of weight on the surfaces intended for that (8). The causes of these deformities include infantile rheumatoid arthritis, osteomyelitis and, in extremely rare cases, parathyroid adenoma (3). There is a significant positive correlation between LDFA values and valgus formation, i.e. varus position. Also, it is important to determine the difference between the femur of the left and right orientation, due to the nature of the dominance of the left and right leg. Namely, the significant majority of people have a dominant left leg and the measured results can show a physiological difference between the angles of the femurs of the left and right dominance. A larger angle leads to denivelation of the condyle in the sense that the lateral condyle is significantly shorter than the medial one, which puts the knee in the so-called *valgus* position. Likewise, a lower LDFA value than the reference leads to denivelation of the condyle to the opposite side so that the medial condyle is smaller than the lateral one by placing the knee in the varus position (10). Numerous sources also state that there is a positive correlation between coxa vara of different etiologies and the formation of *genu valgum* (9, 10).

These findings were compared with a study conducted on the same samples in August and September 2020 at the Niko Miljanić Institute of Anatomy. It was found that one femur was diagnosed as Coxa vara. In accordance with this paper, the same femur is diagnosed as *genu valgum*, which additionally supports the existing scientific research, but the origin of the disorder is not known, which prevents deeper analysis and the drawing relevant conclusions (**Figure 3 and 4**). Guided by the aforementioned definition of *genu varum et valgum*, as well as on the basis of the performed measurements, it is concluded that six right and seven left femurs fell under one of these two diagnoses.

It is again mentioned that due to the lack of appropriate tibia, no definitive conclusion can be drawn about the origin or presence of these disorders.

One femur had a tumor-like growth on the body of unknown histological structure, which is why there is a chance that the tumor played a role in the formation of an angular disorder of the distal end of that femur, but there is not enough information to draw that conclusion (**Figure 5**).

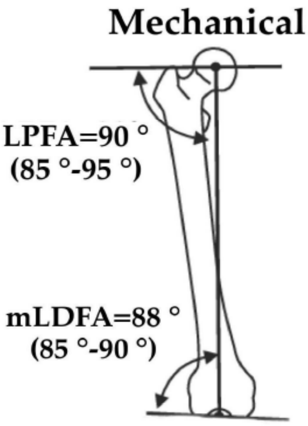


Figure 3. Correlation between Lateral proximal femoral angle (LPFA) and Mechanical lateral distal femoral angle (mLDFA) (See discussion)

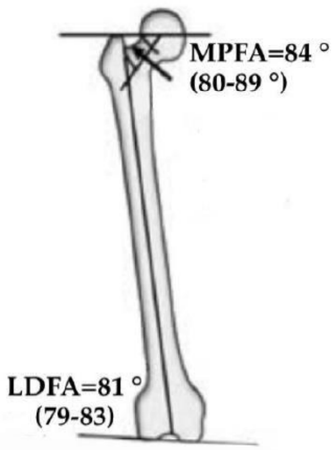


Figure 4. Correlation between angles on the proximal and distal femoral end

Figure 5. Femoral bone with potential tumor changes of unknown histological structure on the outer edge of the body of the femur (**A** - Anterior view; **B** - Posterior view; **C** - Lateral view)

A similar result is present in left femurs, where three femurs can be defined as the *varum gene* and four as the *valgum gene*. The *valgum gene* can also develop as a consequence of environmental risk factors such as e.g., increased amount of fluoride in drinking water (endemic fluorosis), or some congenital diseases such as mucopolysaccharidosis type IV which, in addition to the *valgum gene*, causeing cervical spinal stenosis and hip dysplasia (11, 12). Also, various sources indicate an increased frequency of various angular disorders of the knee joint with surgical repair of femoral fractures (13). One measured sample from the osteological collection shows signs of surgery and placement of nails through the head and large trochanter, but shows no signs of *genu varum* or *genu valgum* despite some scientific papers suggesting an increased risk of angular knee joint disorders during interventions of this nature.

Numerous papers also mention the importance of the medial proximal tibial angle (hereinafter MPTA) for a more precise diagnosis of *valgus* or *varus* knee position (**Figure 6**).

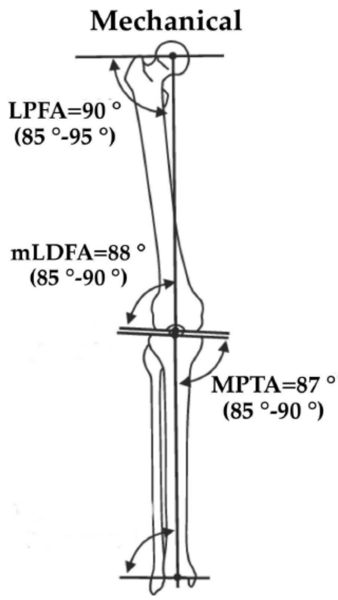


Figure 6. Schematic representation of MPTA

During the conduct of this study, it was not possible to access the appropriate tibiae (*tibia*), which prevented the measurement of MPTA and the establishment of relationships with already measured angles (8, 14). Additionally, postoperative monitoring of MPTA is considered crucial in preventing recurrent varus knee position, where MPTA must be at least 95 degrees (14). There is insufficient evidence that the height of the specimen or the length of the axis of the femur affects in any way the development of angular disorders in the knee joint.

Conclusion

Out of forty-seven examined femurs, by definition, thirteen fall under the above-defined diagnosis of angular disorders of the knee joint. The MAA was above the reference values (above 7 degrees) in two right and four left samples, while it was below 5 degrees in four right and three left measured femurs, but for a more precise diagnosis of disorders of this nature, we also need appropriate tibias to support these hypotheses. These parameters can provide significant insight into the diagnosis and development of congenital and acquired diseases; however, further research is necessary to draw concrete conclusions.

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