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ORIGINAL ARTICLE

MORPHOMETRIC PARAMETERS OF THE PROXIMAL FEMORAL EPIPHYSIS AND THEIR EFFECT ON THE HIP JOINT

MORFOMETRIJSKI PARAMETRI PROKSIMALNOG OKRAJKA BUTNE KOSTI I NJIHOV UTICAJ NA ZGLOB KUKA

Jovan Varda[1], Vanja Valčić[1], Valentina Blagojević[1,2]

[1] Univerzitet u Beogradu, Medicinski fakultet, Beograd, Srbija
[2] Univerzitet u Beogradu, Medicinski fakultet, Institut za anatomiju "Niko Miljanić", Beograd, Srbija

Correspondence: jovanvarda@gmail.com

Abstract

Introduction: The femur is a long bone (*ossa longa*) that forms the hip and knee joints, supporting the weight of almost the entire body. This study is based on analyzing certain angles on the proximal femur that represent anthropometrically and surgically significant parameters, with clinical significance in diseases such as metabolic and degenerative bone disorders, arthritis, various hip trauma and disease.
Aim: Determining the significance of certain morphometric parameters of the proximal femur and exploration of their impact on the hip joint.
Material and methods: This cross-sectional study encompasses measuring four parameters: shaft length, the collodiaphyseal angle (CDA), the medial proximal femoral angle (MPFA) and the lateral proximal femoral angle (LPFA), on adult femora belonging to the archive of the Institute of anatomy „Niko Miljanić“ of the Univerisity of Belgrade, Faculty of Medicine. A digital goniometer precise to two decimal places was used for all measurements.
Results: Forty-seven femora were examined, 25 of which were left and 22 right femora of unknown gender and age, since none of the examined parameters could be used in procuring such information. The average femoral shaft length was 39.9 ± 2.7 cm, the shortest 34.8 cm and the longest 45.7 cm. The Collodiaphyseal angle (CDA) was 127.64 ± 4.25° on average, with the minimum being 119.1° and the maximum 137.7°. Average LPFA was 87.21 ± 3.07°, the lowest 81.6 and the highest 93.0°. Finally, MPFA was 86.9 ± 3.73° on average, with the smallest being 78.7° and the largest 94.5°. The Medial proximal femoral angle of right femora was significantly lower than the MPFA of left femora (p = 0,016).
Conclusion: Eleven samples had a CDA below normal (< 124°), with three being defined as *coxa vara* (CDA < 120°). One had a CDA above normal (> 135°), being defined as *coxa valga*. Outside of reference values, LPFA was determined on 11 samples, being below normal (<85°) in all of them, whilst MPFA had 13 with only one of them being below normal (< 80°).

Keywords:
collodiaphyseal angle,
medial proximal femoral angle,
lateral proximal femoral angle,
coxa vara,
coxa valga

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Sažetak

Uvod: Femur je duga kost (*ossa longa*) koja svojim udelom u zglobu kuka i kolena podržava težinu skoro čitavog tela. Ova studija se zasniva na analizi antropometrijski i hirurški značajnih uglova proksimalnog femura, koji takođe predstavljaju klinički značajnu dijagnostičku indikaciju kod oboljenja poput metaboličkih i degenerativnih bolesti kostiju, artritisa, kao i povreda i oboljenja zgloba kuka.

Cilj je proučavanje morfometrijskih parametara proksimalnog okrajka femura i načina na koji oni uslovljavaju razvojne promene na zglobu kuka.

Materijal i metode: Ova studija preseka obuhvata određivanje četiri parametra, dužinu osovine femura (*femoral shaft*), kolodijafizni ugao (engl. *collodiaphyseal angle, CDA*), medijalni proksimalni femoralni ugao (engl. *medial proximal femoral angle, MPFA*) i lateralni proksimalni femoralni ugao (engl. *lateral proximal femoral angle, LPFA*) na adultnim femurima iz arhivske zbirke Instituta za anatomiju „Niko Miljanić" Medicinskog fakulteta u Beogradu. Za sva merenja je upotrebljen digitalni goniometar sa preciznošću merenja na drugu decimalu.

Rezultati: Ispitano je 47 femura, među kojima su 25 levih i 22 desna adultna femura nepoznatog pola i starosti, budući da se ispitivanim parametrima nisu mogli odrediti ovi podaci. Prosečna dužina osovine femura iznosila je 39,9 ± 2,7 cm, minimalna 34,8 cm, a maksimalna 45,7 cm. Prosečni *CDA* iznosio je 127,64 ± 4,25°, minimalni 119,1°, a maksimalni 137,7°. Prosečni *LPFA* iznosio je 87,21 ± 3,07°, najniže vrednosti 81,6°, a najviše 93,0°. Prosečni *MPFA* iznosio je 86,9 ± 3,73°, minimalni 78,7°, a maksimalni 94,5°. Jedina pronađena statistički značajna devijacija je *MPFA* desnih femura, statistički značajno manji od *MPFA* levih femura (p = 0,016).

Zaključak: Među ispitanim uzorcima 11 femura ima *CDA* ispod normalne vrednosti (< 124°), od kojih se 3 mogu definisati kao *coxa vara* (*CDA* < 120°). Kolodijafizni ugao iznad referentne vrednosti (> 135°) poseduje samo jedan uzorak i on se može definisati kao *coxa valga*. Odstupanja od referentnog opsega za *LPFA* je bilo 11 i svi su bili ispod donje granice (< 85°), dok je za *MPFA* bilo 13, samo sa jednim ispod donje granice (< 80°).

Ključne reči:
kolodijafizni ugao,
medijalni proksimalni femoralni ugao,
lateralni proksimalni femoralni ugao,
coxa vara,
coxa valga

Introduction

The femur is the longest and largest bone in the human body. It is classified as a long (*ossa longa*), paired bone, and represents the only bone of the femoral region. It takes part in forming the hip (*art. coxae*) and knee (*art. genu*) joints and thus supporting the weight of nearly the entire body, transferring it onto the tibia. Like any other *ossa longa*, the femur possesses a body (*diaphysis*) and two ends (*epiphysis*), connected by *metaphyses*. The body of the femur consists of the anterior, medial and lateral sides, limited by the medial, lateral and posterior edges. Notable structures on the proximal end of the femur include the femoral head (*caput femoris*) and anatomical neck of the femur (*collum femoris*), as well as the greater and lesser trochanter (*trochanter major et minor*). These structures all take part in forming morphometric parameters examined in this study (1).

The before mentioned hip joint is formed mainly by the head of the femur and the acetabulum of the hip bone. The acetabulum alongside a fibrocartilagenous surrounding it represents the first stabilizing structure of the hip, decreasing the chance of dislocation of this joint. Further stabilizers of the hip include the joint capsule and various ligaments and muscles, with ligaments being dominant anteriorly and muscles posteriorly. Alongside these structures, certain morphometric parameters are crucial in proximal femoral growth and development and can result in hip deformities called *coxa vara* and *coxa valga* (1, 2).

During early skeletal development, the femoral head and greater trochanter develop from a single physis which later diverges. The capital physis develops further, forming an angle between the femoral head and neck and the anatomical axis that's physiologically between 124 and 135° (3). In case of abnormal development of the femur, deformities named *coxa vara* and *coxa valga* are found.

Coxa vara is a hip deformity, where the angle between the femoral head and the anatomical axis is smaller than 120° (1–5). On the other hand, an angle greater than 135° is defined as *coxa valga* (1, 2, 5). Both deformities result in aberrant leg development, weakness of the hip joint and surrounding musculature and could originate in very early development, as a consequence of injury or surgical intervention, as well as diseases such as idiopathic or postseptic arthritis (6), metabolic bone diseases such as Paget's disease, osteomyelitis, neuromuscular diseases (e.g. cerebral paralysis, spinal dysraphism), tumors and degenerative bone diseases (arthroses) (3, 7, 8).

The aim of this study is to examine the significance of certain morphometric parameters of the proximal femur that are present in various changes in all age groups, from early skeletal development to adulthood, taking into consideration potential changes on the femora themselves.

Material and methods

In this cross-sectional study, the used femora originate from the archive of the Institute of anatomy „Niko Miljanić" of the University of Belgrade, Faculty of Medicine, with the total of forty-seven analyzed femora, out of which 25 are left and 22 right (**Figure 1**).

Figure 1. Photograph of the entire archive of femora from the Institute of anatomy „Niko Miljanić" of the University of Belgrade, Faculty of Medicine.

The exact age and genders of cadavers that the femora originate from were unknown. The four examined morphometric parameters are:

1. Length of the anatomical axis of the femur or the femoral shaft – defined as a line made up of points on top of the greater trochanter on the proximal end, and the center of the intercondylar line of the distal end. Another parameter used, but not measured in this study is the mechanical femoral shaft, a line that passes through points on the center of the femoral head proximally and the middle of the intercondylar line distally (1);

2. Collodiaphyseal angle - CDA – the angle between the femoral shaft and a line passing through the centre of the femoral head and neck (2);

3. Medial proximal femoral angle - MPFA – the angle that the femoral shaft forms with the line between the femoral head and the top of the greater trochanter (9);

4. Lateral proximal femoral angle - LPFA – similar to the MPFA, this angle consists of the line between the centre of the femoral head and the top of the greater trochanter and the above mentioned mechanical shaft (4, 9).

The length of the femoral and mechanical shaft depends on the age and height of the person, as well as any already existing conditions and deformities, and thus no values were taken as references for these parameters.

The physiological value of CDA varies depending on the author, most often between 120-130° (3), 124-136° (4), 120-135° (1, 2, 5), and this study uses the third one. Accordingly, all CDA values lesser than 120°are defined as *coxa vara* (1), while values greater than 135° represent *coxa valga* (4). The physiological value for MPFA is most commonly 80-89°, while LPFA varies either between 85-90° or 85-95°, with the second range being chosen in this study. The examined parameters affect one another as shown on the figure below (**Figure 2**).

All of the values taken for reference were chosen as the ones most commonly found in literature in orthopedics, orthopedic surgery and radiology (10). All of the measurements were conducted using a digital goniometer (Iskra 5422-200) with the capability of measuring up to the second decimal. For all further statistical processing, the statistical software platform SPSS, version 25, was used, with Pearson correlation being the processing method for obtaining the r value and the T test for the p value.

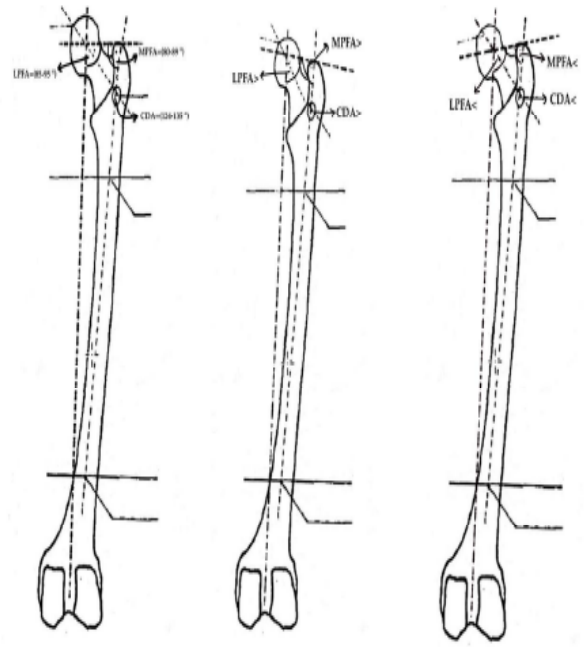

Figure 2. Physiological values and the relationship between examined parameters

Results

Femoral shaft length was determined to be 39,9±2,7 cm, with the shafts of the left femora being 39,41±2,60 cm, and of the right femora 40,48±2,82 cm, on average. The shortest femoral shaft length measured was 34,8 cm, and the longest one 45,7 cm (**Figure 3**).

No statistically significant difference was found between shaft lengths of left and right femora (p=0,183) (Table 1). Average CDA measured was 127,64±4,25°, with the average CDA of the left femora being 127,84°, and the CDA of the right femora being 127,42°. The smallest measured CDA was 119,1° and the largest was 137,7°. The average lateral proximal femoral angle was determined to be 87,21±3,07°, with a minimum value of 81,6°, and a maximum value of 93,0°. LPFA of the left femora was determined to be 87,05±2,99, while LPFA of the right femora was 87,40±3,23° on average, with no statistically significant difference between the two values (p = 0,694) (**Table 1**). The average medial proximal femoral angle measured was 86,9±3,73°, with values ranging from 78,7 to 94,5°. Average

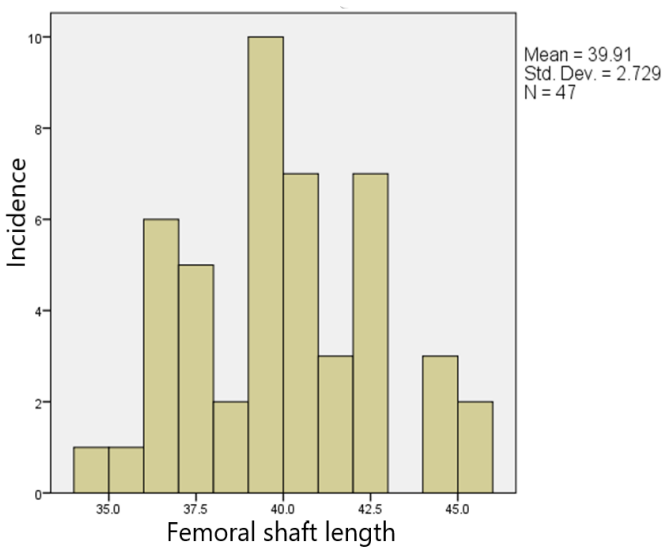

Figure 3. Histogram of incidence (shown on the y axis) of different femoral shaft lengths (shown on the x-axis).

MPFA values of left and right femora were 88,11±3,86 and 85,52±3,13, respectively, with the MPFA of the right femora being statistically significantly smaller than that of th left femora (p = 0,016) (**Table 1**).

No statistically significant correlation between femoral shaft length, CDA and LPFA values was found (p > 0,05) (**Table 2**).

Discussion

Based on the analyzed measurements, 11 of the samples were determined to have a CDA value below 124°, three of which fall under the definition of *coxa vara* (CDA<120°) (11). *Coxa valga* was found on only one femur. Eleven LPFA values outside of the range of reference were found and all were smaller than 85°, while thirteen deviations of MPFA were found, only one of which was smaller than 80°, with the rest being larger than 89° (4). Smaller MPFA and LPFA could be a consequence of multiple factors and as such could be significant in orthopedic surgery (10–12).

Two instances of lower CDA values coincided with lower LPFA values but none fell under the definition of *coxa vara*. On the other hand, the only femur with a *coxa valga* collodiaphyseal angle also possessed an LPFA above normal (>95°) which could implicate a possible correlation between the two. Larger medial proximal femoral angles were accompanied by lower CDA values on three occasions, two of which could be described as *coxa vara*. This could also be a possible correlation between greater MPFA values and the *varum* hip deformity. The above-mentioned correlation would, after further examination, have a potential application in radiological diagnostics, especially in cases of *coxa vara* being present in conditions such as postseptic, osteopathic or idiopathic arthritis (3, 6, 7), chondrodysplasia (12, 13), as well as with patients with camptodactily-arthropathy-*coxa vara*-pericarditis syndrome (CACP) (14, 15). Another potential application could be found in orthopedic surgery, as a supplementary diagnostic parameter for osteotomies and implant placements, both preoperatively and postoperatively (3, 4, 10, 11). *Coxa valga* alongside LPFA could prove to be a set of radiological diagnostic parameters useful when diagnosing certain mucopolyaccharidoses (16), hip

Table 1. Average femoral shaft, LPFA and MPFA values of left and right femora

Variable	Left femora	Right femora	p value (Pearson correlation)
Femoral shaft length	39,41±2,60	40,48±2,82	0,183
LPFA	87,05±2,99	87,40±3,23	0,694
MPFA	88,11±3,86	85,52±3,13	**0,016***

Table 2. Correlations between femoral shaft lengths, collodiaphyseal and lateral proximal femoral angles

Correlations				
		Femoral shaft length	CDA	LPFA
Femoral shaft length	Pearson correlation		-.170	.007
	Sig. (2-tailed)		.254	.961
	N		47	47
Collodiaphyseal angle	Pearson correlation	-.170		-.262
	Sig. (2-tailed)	.254		.075
	N	47		47
Lateral proximal femoral angle	Pearson correlation	.007	-.262	
	Sig. (2-tailed)	.961	.075	
	N	47	47	

subluxation as a result of cerebral paralysis (8), as well as in orthopedic surgery in a way similar to *coxa vara* (4). Four samples were found possessing aberrant MPFA and LPFA values together, but none of those coincided with abnormal CDA values.

Two samples were examined with potential tumors of unknown histological structure, one of which was present on the lateral edge of the femoral body and another on the lateral proximal end (**Figures 4 and 5**). Both of these femora had an MPFA value above normal, as well as CDA in a *varus* position. There is a possibility of these tumors being the cause of present deformities. *Varus* and *valgus* deformities also directly affect the positioning between the head of the femur and the acetabulum. This results in a change of contact surface between the two, altering the weight applied onto the mechanical shaft of the femur. The assumption that follows is that greater LPFA values, alongside the *coxa valga* deformity, increase the burden on the mechanical shaft and increase the risk of hip injury and dislocation (8, 17).

Examined angles, alongside the hip, also have an effect on the knee joint. It is theorized that *coxa vara* and *coxa valga* correlate to knee deformities of *genu valgum* and *genu varum* by directly affecting corresponding

Figure 4. The femur with changes of unknown histological changes present on the proximal epiphysis

Figure 5. Femur with a potential tumor of unknown histological structure on the lateral edge of its body

morphometric parameters of the distal femur. In accordance with another study simultaneously conducted on the Institute of anatomy „Niko Miljanić“ on the same archival samples, one of the samples determined to possess the *genu varum* deformity matches the sample described as *coxa valga* in this study. Considering the fact that this was found on only one of the samples, any claim of causation would be unfounded, even though such claims can already be found and substantiated with this study (16,18). This causality could also find application in orthopedic surgery, mostly postoperatively after implantations and osteotomies (4,18), as well as with the already confirmed correlation between *coxa valga* and severe cases of osteopathic arthritis, where CDA is a supplementary predictive parameter (17). The main limiting factor of this study would be the fact that the age and gender of examined femora were unknown, as well as the corresponding tibiae being unavailable.

Conclusion

Out of 47 examined femora, three were determined to be *coxa vara* with collodiaphyseal angles smaller than 120°, and only one as *coxa valga*, with CDA greater than 135°. Additionally, MPFA values above normal concur with *coxa vara* on two occasions. The only sample described as *coxa valga* was also the only femur with LPFA above reference values. Further examination is required to definitively confirm any of these correlations.

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