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ARAŞTIRMA / RESEARCH

Femur morphometry and correlation between proximal and distal parts

Femur morfometrisi ve proksimal ile distal parçalar arasındaki korelasyon

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Abstract

Purpose: The harmony of the morphometric features of the proximal and distal parts of the femur is very important in terms of biomechanical function. The aim of the study is to examine the correlation between the proximal and distal parts of the femur and to produce regression formulas for implant design with morphometric properties in harmony.
Materials and Methods: The study was carried out on 33 dry femurs in the bone collection of Harran University Faculty of Medicine, Department of Anatomy. Four parameters related to femur length and segments, sixteen parameters related to proximal femur and sixteen parameters related to distal femur were measured. Statistically, descriptive statistics, correlation and linear regression analyzes were made.
Results: Entire femur length was 400.27 ± 39.15 mm, diameter of femur neck was 32.82 ± 3.37 mm, inclination angle was 134.11 ± 6.25, declination angle was 17.28 ± 7.53, transcondylar axis length was 78.37 ± 5.49 mm, medial posterior condyle width was 27.83 ± 2.37 mm, lateral posterior condyle width was 26.77 ± 1.54 mm, intercondylar notch width was 18.61 ± 2.67 mm, and intercondylar notch depth was 23.23 ± 5.22 mm found.
Conclusion: We believe that the data we have obtained will benefit orthopedists and implant manufacturers on the issue of that the parts of the femur should be in harmony for biomechanical function and this compatibility should be taken into account when designing the implant, and also forensic scientists and anthropologists in identification.
Keywords:. Distal femur, femur, identification, proximal femur

Öz

Amaç: Femurun proksimal ve distal kısımlarının morfometrik özelliklerinin uyumu biyomekanik fonksiyon açısından çok önemlidir. Çalışmanın amacı, femurun proksimal ve diatal kısımları arasındaki ilişkiyi incelemek ve uyum içinde morfometrik özelliklere sahip implant tasarımı için regresyon formülleri üretmektir.
Gereç ve Yöntem: Çalışma Harran Üniversitesi Tıp Fakültesi Anatomi Anabilim Dalı kemik koleksiyonunda bulunan 33 kuru femur üzerinde gerçekleştirildi. Femur boyu ve segmentler ile ilgili dört, proksimal femur ile ilgili onaltı ve distal femur ile ilgili onaltı parametre ölçüldü. İstatistiksel olarak, tanımlayıcı istatistik, korelasyon ve lineer regresyon analizleri yapıldı.
Bulgular: Çalışmanın sonucunda, toplam femur uznluğu 400.27 ± 39.15 mm, collum femoris çapı 32.82 ± 3.37 mm, inklinasyon açısı 134.11 ± 6.25, deklinasyon açısı 17.28 ± 7.53, transkondiler eksen uzunluğu 78.37 ± 5.49 mm, condylus medialis arka genişliği 27.83 ± 2.37 mm, condylus lateralis arka genişliği 26.77 ± 1.54 mm, fossa intercondylaris genişliği 18.61 ± 2.67 mm, fossa intercondylaris derinliği 23.23 ± 5.22 mm bulundu.
Sonuç: Femur'un bölümlerinin biyomekanik fonksiyon için uyumlu olması ve bu uyumluluğun implant tasarlanırken dikkate alınması gerektiği konusunda elde ettiğimiz verilerin ortopedistlere ve implant üreticilerine, ayrıca kimliklendirmede adli bilimcilere ve antropologlara fayda sağlayacağı kanaatindeyiz.

Anahtar kelimeler: Distal femur, femur, kimliklendirme, proksimal femur

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INTRODUCTION

The femur, which has two ends as superior and inferior and a shaft, is the longest and strongest bone in the human body. The superior end of the femur has a head, neck, and two trochanters as greater and lesser. At its inferior end, the femur has two condyles as lateral and medial, separated by an intercondylar notch. The femur transmits body weight from the hip bone to the tibia in a standing position[1,2]. The structure of the proximal part, which serves as the cornerstone of human mobility, allows the leg to move in three dimensions relative to the human body[3].

The femur has joints such as the hip joint at the superior end; knee joint at the inferior end. The head of the femur and acetabulum forms the synovial hip joint on the proximal end. Distally, there is the patellofemoral joint between the femur and the patella, and the tibiofemoral joint between the femur and the tibia[4,5,6].

Correct orientation of the femoral neck and femoral head is essential for the biomechanical function of the hip joint. Two important aspects of this orientation are the inclination angle and the femoral version. The inclination angle is formed by the femoral neck axis and the femoral shaft axis in the frontal plane. The femoral version is defined as the anterior deviation of the neck axis from the posterior condylar line[7].

The anatomical structure of the femur may differ according to ethnic origins, age and gender. It may even differ in people living in different geographical regions within the same population[4,8,9,10]. In many aspects, the femur is of interest to many disciplines such as anatomy, anthropology, forensic sciences, human kinematics and orthopedics[4,8,11]. Anatomical studies of the femur provide useful data for detecting the changes that may be seen in osteoporosis, associated congenital anomalies of the femur, and understanding the clinical disease conditions, including the common fracture site, as well as forensic cases[3].

The aim of the study was to develop regression formulas for determining the appropriate dimensions for proximal and distal end morphometry for total femoral prostheses for surgical uses. For the benefit of forensic science, to develop regression formulas for estimating age, gender, ethnicity, and height to complete missing segments of the fragmented femur. We believe that the formulas we have developed will be beneficial for anthropologists, forensic scientists, orthopedics and industrial areas that will produce femoral prostheses.

MATERIALS AND METHODS

The study was conducted on 33 dry femurs (14 right, 19 left) of unknown gender and age, belonging to the bone collection of Harran University Faculty of Medicine, Department of Anatomy. The ethics committee approval was not required since the bone collection used in anatomy lessons as course material was used in current study. The bones that were intact and did not have any malformations were included in the study.

Four parameters related to entire femur height and segment lengths, sixteen parameters on proximal femur and sixteen parameters on the distal femur were evaluated. For the linear measurements (F1, F2, F3, F4, P1, P2, P3, P4, P5, P6, P7, P8, P11, P12, P13, P14, P15, D1, D2, D3, D4, D5, D6, D7, D8, D9, D10, D11, D12, D13, D14, D15, D16) a digital caliper was used. For the angular measurements (P9, P10, P16), the photographs of the bones were taken and transferred them to the computer. The angular measurements were evaluated using Image J software (Ver. 1.51 23 April 2018). The parameters measured related to entire height and segment lengths were given in table 1. The parameters measured on the proximal femur were given in table 2. The parameters measured on the distal femur were given in table3.

Table 1. Parameters measured related to entire height and segment lengths (mm)

Parameters	Description of the parameters
F1	Entire femur length
F2	Distance between proximal end of greater trochanter and distal end of condyles
F3	Femur shaft length
F4	Condylar segment length

The parameters related to F1-F4 were given in figure 1.

Figure 1. Parameters measured related to entire height and segment lengths

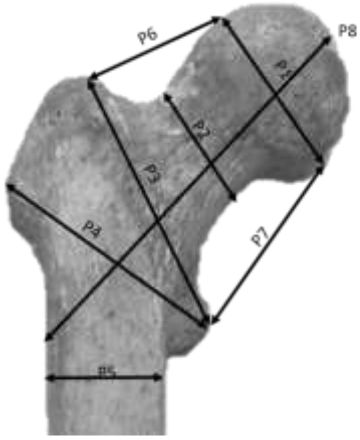

Figure 2. Parameters measured on the proximal femur

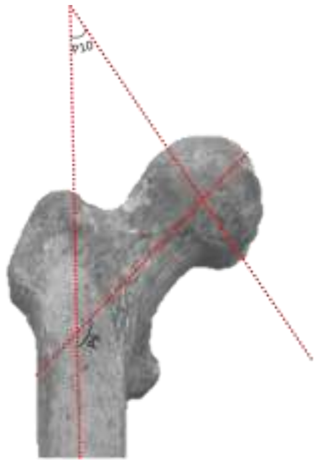

Figure 3. Parameters measured on the proximal femur

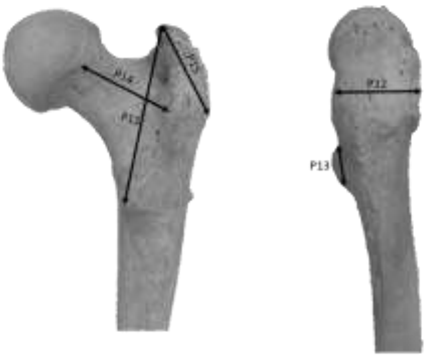

Figure 4. Parameters measured on the proximal femur

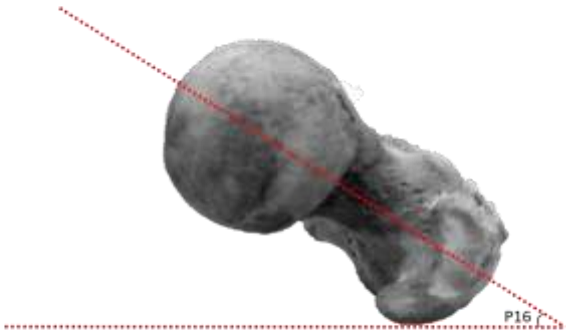

Figure 5. Angle of femoral neck Anteversion (Declination angle)

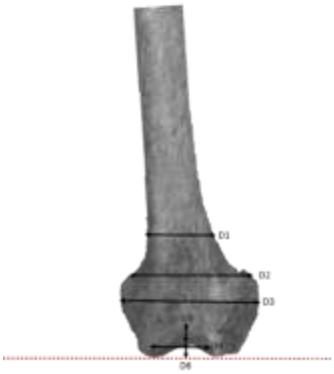

Figure 6. Parameters measured on the distal femur

Figure 7. Parameters measured on the distal femur

Table 2. Parameters measured on the proximal femur (mm)

Parameters	Description of the parameters
P1	Maximum vertical diameter of femur head
P2	Diameter of femur neck
P3	Distance between superior aspect of greater trochanter and tip of lesser trochanter
P4	Distance between inferior aspect of greater trochanter and tip of lesser trochanter
P5	Proximal segment diameter of femur shaft
P6	Distance between proximal tip of the greater trochanter and head of femur
P7	Distance between tip of the lesser trochanter and head of femur
P8	Femoral neck axis length
P9	Neck-shaft angle (Inclination angle)
P10	Alsberg angle
P11	Length of the intertrochanteric line
P12	Width of greater trochanter
P13	Width of lesser trochanter
P14	Length of the femur neck
P15	Length of greater trochanter
P16	Angle of femoral neck anteversion (Declination angle)

The parameters related to P1-P8 were given in figure 2; the parameters related to P9, P10 were given in figure 3; the parameters related to P11-P15 were given in figure 4; the parameter of P16 were given in figure 5.

Table 3. Parameters measured on the proximal femur (mm)

Parameters	Description of the parameters
D1	Distal segment diameter of femur shaft
D2	Horizontal width of supracondylar line
D3	Transcondylar axis length
D4	Width of patellofemoral joint surface
D5	Height of patellofemoral joint surface
D6	Depth of trochlear groove
D7	Medial posterior condyle width
D8	Lateral posterior condyle width
D9	Medial posterior condyle height
D10	Lateral posterior condyle height
D11	Mediolateral width
D12	Medial antero-posterior length
D13	Lateral antero-posterior length
D14	Intercondylar notch width
D15	Intercondylar notch depth
D16	Intercondylar (sulcus) line antero-posterior length (D11-16; Figure 8)

The parameters related to D1-D16 were given in figure 6; the parameters related to D7-D10 were given in figure 7; the parameters related to D11-D16 were given in figure 8.

Table 4. The findings of the parameters related to femur length (mm)

Parameters (mm)	Minimum	Maximum	Mean ± SD
F1. Entire femur length	324.95	475.32	400.27 ± 39.15
F2. Distance between proximal end of greater trochanter and distal end of condyles	312.98	441.41	376.89 ± 36.39
F3. Femur shaft length	251.69	357.44	304.55 ± 30.71
F4. Condylar segment length	32.62	51.21	42.75 ± 4.65

Table 5. The findings of the parameters related to the proximal part of the femur (mm)

Parameters (mm)	Minimum	Maximum	Mean ± SD
P1. Maximum vertical diameter of femur head	39.60	50.80	45.46 ± 3.02
P2. Diameter of femur neck	25.10	39.80	32.82 ± 3.37
P3. Distance between superior aspect of greater trochanter and tip of lesser trochanter	53.40	75.20	65.28 ± 6.51
P4. Distance between inferior aspect of greater trochanter and tip of lesser trochanter	44.90	68.10	56.76 ± 6.34
P5. Proximal segment diameter of femur shaft	28.30	37.20	32.96 ± 2.41
P6. Distance between proximal tip of the greater trochanter and head of femur	17.60	35.30	26.88 ± 4.39
P7. Distance between tip of the lesser trochanter and head of femur	26.50	51.50	39.99 ± 6.58
P8. Femoral neck axis length	83.50	104.10	94.26 ± 5.82
P9. Neck-Shaft angle (Inclination angle)	123.69	148.11	134.11 ± 6.25
P10. Alsberg angle	33.48	61.93	45.13 ± 5.79
P11. Length of the intertrochanteric line	52.90	77.90	66.00 ± 7.35
P12. Width of greater trochanter	30.40	45.80	37.66 ± 4.22
P13. Width of lesser trochanter	18.30	27.30	22.49 ± 2.19
P14. Length of the femur neck	36.40	55.30	44.22 ± 4.62
P15. Length of greater trochanter	19.20	34.60	26.56 ± 3.93
P16. Angle of femoral neck Anteversion (Declination angle)	0.83	40.95	17.28 ± 7.53

Table 6. The findings of the parameters related to the distal part of the femur (mm)

Parameters (mm)	Minimum	Maximum	Mean ± SD
D1. Distal segment diameter of femur shaft	38.10	54.10	45.39 ± 4.15
D2. Horizontal width of supracondylar line	58.70	79.10	69.97 ± 5.45
D3. Transcondylar axis length	66.80	86.40	78.37 ± 5.49
D4. Width of patellofemoral joint surface	32.80	44.40	37.62 ± 3.09
D5. Height of patellofemoral joint surface	17.20	28.50	22.56 ± 3.06
D6. Depth of trochlear Groove	3.40	7.60	4.98 ± 1.19
D7. Medial posterior condyle width	24.10	33.40	27.83 ± 2.37
D8. Lateral posterior condyle width	23.10	29.50	26.77 ± 1.54
D9. Medial posterior condyle height	26.20	43.70	36.98 ± 4.07
D10. Lateral posterior condyle height	29.30	43.10	36.71 ± 3.32
D11. Mediolateral width	53.20	69.80	62.89 ± 5.01
D12- Medial antero-posterior length	51.20	65.80	59.16 ± 3.65
D13- Lateral antero-posterior length	54.10	68.80	59.49 ± 3.33
D14. Intercondylar notch width	13.80	24.40	18.61 ± 2.67
D15. Intercondylar notch depth	22.30	30.20	23.23 ± 5.22
D16. Intercondylar (sulcus) line antero-posterior length	22.30	36.60	28.04 ± 3.30

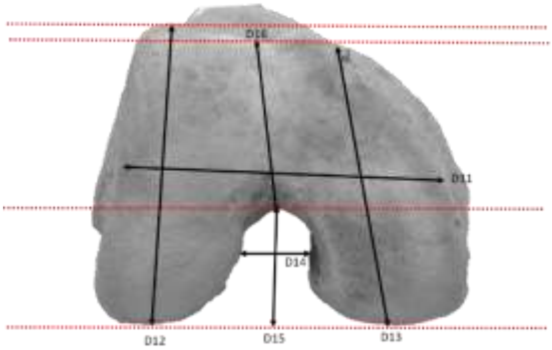

Figure 8. Parameters measured on the distal femur

Table 7. The correlation analysis findings between the proximal and distal parts of the femur

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16
D1	.254	.496**	.100	.302	.362*	.234	-.089	.256	.350	.090	.139	.433*	.300	.022	.221	.227
	.176	.005	.635	.143	.046	.230	.655	.172	.068	.649	.509	.024	.121	.917	.241	.237
D2	.654**	.680**	.407*	.373	.254	.150	.101	.477*	-.05	-.07	.575**	.126	.347	.270	.356	-.245
	<.001	<.001	.048	.073	.192	.466	.624	.012	.985	.751	.003	.547	.083	.203	.068	.218
D3	.763**	.695**	.538**	.512*	.221	.188	.325	.667**	.027	-.15	.670**	.325	.347	.410*	.404*	-.164
	<.001	<.001	.007	.010	.267	.367	.113	<.001	.896	.484	<.001	.112	.089	.047	.041	.423
D4	.623**	.315	.551**	.622**	.148	.050	.467*	.567**	-.08	-.11	.648**	.409*	.360	.421*	.089	.046
	.001	.117	.005	.001	.461	.813	.019	.003	.713	.595	.001	.042	.077	.040	.666	.823
D5	.490*	.267	.011	.371	-.015	.406*	.067	.502**	.005	.014	-.082	.193	.239	.124	.200	.102
	.011	.188	.960	.074	.941	.044	.751	.009	.981	.944	.704	.356	.249	.562	.327	.620
D6	.019	-.045	.225	.168	.208	-.240	-.207	.092	-.23	- .21	.321	.141	-.235	.423*	.458*	-.49*
	.928	.828	.291	.433	.297	.249	.322	.656	.234	.311	.126	.500	.257	.040	.019	.038
D7	.087	-.001	-.099	.035	-.037	.065	-.223	-.201	-.17	-.33	-.042	.073	-.064	.203	-.074	-.131
	.671	.996	.646	.870	.853	.758	.284	.324	.414	.103	.845	.729	.761	.342	.721	.532
D8	.554**	.439*	.305	.290	.253	-.205	.010	.267	.137	.104	.160	.420*	.253	.449*	.239	.036
	.003	.025	.147	.169	.202	.327	.961	.187	.505	.612	.456	.037	.223	.028	.239	.862
D9	.656**	.690**	-.015	.334	.363	-.060	-.195	.385*	.193	-.05	.063	.494*	.471*	.299	.365	-.002
	<.001	<.001	.944	.111	.053	.773	.340	.043	.325	.786	.772	.012	.015	.156	.056	.992
D10	.812**	.701**	.280	.620**	.322	-.005	-.048	.569**	.156	-.01	.155	.651**	.544**	.566**	.356	.045
	<.001	<.001	.186	.001	.094	.980	.816	.002	.437	.976	.470	<.001	.004	.004	.069	.823
D11	.584**	.201	.377	.280	.099	.159	.235	.402*	-.15	-.16	.523**	.152	.072	.296	.128	-.022
	.002	.324	.069	.185	.623	.447	.257	.042	.480	.445	.009	.469	.734	.160	.532	.917
D12	.820**	.592**	.515*	.703**	.201	.225	.395	.716**	.061	-.07	.531**	.340	.572**	.484*	.332	-.036
	<.001	.001	.010	<.001	.314	.280	.051	<.001	.766	.740	.008	.097	.003	.017	.097	.862
D13	.835**	.603**	.336	.583**	.402*	.107	.154	.691**	-.08	-.10	.392	.458*	.396	.558**	.463*	-.138
	<.001	.001	.109	.003	.038	.610	.463	<.001	.702	.622	.058	.021	.050	.005	.017	.502
D14	-.331	-.259	-.094	-.422*	-.129	-.244	-.157	-.033	.173	.160	-.044	-.128	-.115	-.123	.156	.060
	.092	.193	.663	.040	.513	.239	.454	.869	.389	.426	.837	.540	.584	.566	.436	.772
D16	.389*	.223	.013	.433*	.123	.219	.169	.472*	.020	-.30	.164	.140	.279	.354	.513**	-.298
	.041	.255	.952	.035	.525	.283	.409	.011	.920	.117	.443	.504	.167	.090	.005	.132

First line- Pearson's correlation coefficient; Second line- p value

Table 8. The comparison of the femoral neck-shaft angle value with other studies

Author	Year	Population	Value
Isaac et al.[16]	1997	South Africa	126.7°
Mahaisavariya et al.[20]	2002	Thailand	128.04°
Vaishnani et al.[21]	2019	India	137.2 ± 5.1°
İyem et al.[22]	2002	Turkey	30.4 ± 5.1°
Yoshioka et al.[23]	1987	Canada	131°
Current Study	2021	Turkey	134.11 ± 6.25°

Statistical analysis

A power analysis to determine sample size was based on to determine the correlation between the morphometric features of the proximal and distal end of the femur. Using a two sided test, 5% significance level test (α=0.05) with power 80% power (β=0.2) for 0.75 effect size, the required sample size is approximate 33 (n=33).

We performed statistical analyzes using IBM SPSS version 20.0 (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.). We conducted descriptive statistical analyzes (minimum, maximum, mean and standart deviation) using the data we obtained from the femur as a result of the measurements. We performed Pearson correlation analysis to examine the relationship between the morphometric values of the femur. We developed linear regression formulas to predict the femur length, morphometric values of proximal and distal parts of the femur. We accepted the significant value as <0.05 for statistical analysis.

RESULTS

The findings of the parameters related to femur length were given in Table 4. The findings of the parameters related to the proximal part of the femur were given in table 5. The findings of the parameters related to the distal part of the femur were given in table 6. The correlation analysis findings between the proximal and distal parts of the femur were given in table 7.

The regression equations in order to estimate the entire stature of the femur (mm) by the morphometry of the proximal and distal parts of the femur: All variables will be taken into account in millimeters.

F1= 202.914 – (8.951 x P1) + (2.731 x P10) + (6.015 x P12) + (7.358 x D6) + (4.295 x D7) – (12.980 x D8) + (7.814 x D12)

Adjusted R^2= 0.509, Standard Error of the Estimate= 23.789

The regression equations in order to estimate the dimensions of the proximal part of the femur (mm) by the morphometry of the distal part of the femur and femur length: All variables will be taken into account in millimeters.

Linear regression analysis examines the relationship between dependent variable (y) and independent variable(s) (x,.). It is formulated such as Y=a+bX or Y=B0+B1X. The value of the other is found when the value of one of the variables is known. The conformity indicator of the model is expressed as R^2, and the closer the R^2 value is to 1, the better the model[12].

P1= 0.226 - (0.497 x D6) + (0.440 x D10) + (0.134 x D11) + (0.391 x D13)

Adjusted R^2= 0.841, Standard Error of the Estimate= 1.085

P2= -10.489 + (0.296 x D2) + (0.606 x D10)

Adjusted R^2= 0.621, Standard Error of the Estimate= 2.054

P3= -25.488 + (0.876 x D3) + (0.404 x P4) – (0.114 x D6) – (0.712 x D7) + (2.092 x D8) – (1.003 X D9)

Adjusted R^2= 0.637, Standard Error of the Estimate= 3.763

P4= -27.044 + (1.404 xD12)

Adjusted R^2= 0.472, Standard Error of the Estimate= 4.675

P5= 21.537 + (0.258 x D1)

Adjusted R^2= 0.294, Standard Error of the Estimate= 1.610

P6= 42.191 + (0.823 x D5) – (1.265 x D8)

Adjusted R^2= 0.260, Standard Error of the Estimate= 3.547

P7= 32.356 + -(0.363 xD1) + (1.363 x D3) + (1.743 x D4) + (1.091 x D8) - (0.939 x D9) – (1.299 x D10) – (1.316 x D11) – (0.610 x D14)

Adjusted R^2= 0.613, Standard Error of the Estimate= 4.076

P8= 2.587 + (0.496 x D3) + (1.027 x D4) + (1.605 x D5) + (0.894 x D6) – (0.844 xD7) + (0.440 x D8) – (0.773 x D10) – (0.604 x D11) + (0.587 x D13) + (0.868 x D14)

Adjusted R^2= 0.781, Standard Error of the Estimate= 2.526

P9= 121.705 + (1.249 x D1) – (0.526 x D2) – (1.149 x D4) – (2.685 x D6) – (2.539 x D7) + (2.284 x D8) – (0.593 x D10) + (1.093 x D11) – (0.606 x D12) + (0.627 x D15) + (1.152 x D16)

Adjusted R^2= 0.533, Standard Error of the Estimate= 4.206

P10= 18.241 + (0.741 x D1) – (0.180 x D3) – (1.183 x D6) – (1.099 x D7) + (2.559 x D8) – (0.882 x D9) + (0.442 x D14)

Adjusted R^2= 0.156, Standard Error of the Estimate= 5.568

P11= -58.514 + (1.210 xD2) + (1.365 x D4) – (0.749 x D7) + (1.247 x D8) – (1.030 x D9) + (0.655 x D14)

Adjusted R^2= 0.747, Standard Error of the Estimate= 3.559

P12= -24.760 – (0.648 x D2) + (0.472 x D4) + (0.990 x D8) + (0.682 x D9) + (0.531 x D13) + (0.350 x D14)

Adjusted R^2= 0.510, Standard Error of the Estimate= 3.004

P13= -8.811 + (0.482 x D4) – (0.011 x D6) + (0.640 x D7) – (0.470 x D11) + (0.568 x D12) + (0.309 x D14) – (0.222 x D15) – (0.310 x D16)

Adjusted R^2= 0.646, Standard Error of the Estimate= 1.523

P14= -64.481 – (0.579 x D2) – (0.542 x D5) + (0.805 x D6) + (0.478 x D7) + (1.844 x D8) + (1.009 x D12) + (0.453 x D13) + (0.449 x D14)

Adjusted R^2= 0.485, Standard Error of the Estimate= 3.360

P15= -33.493 – (0.406 x D4) + (0.388 x D5) + (1.518 x D6) + (0.363 x D8) – (0.459 x D10) + (0.554 x D12) + (0.371 x D13) + (0.631 x D14)

Adjusted R^2= 0.322, Standard Error of the Estimate= 3.157

P16= 19.359 + (1.389 x D1) – (0.818 x D2) – (0.631 x D3) – (0.705 x D4) – (4.156 x D6) – (2.143 x D7) + (1.819 x D8) + (1.611 x D11) – (0.552 x D12) + (0.527 x D15) + (0.671 x D16)

Adjusted R^2= 0.507, Standard Error of the Estimate= 5.618

The regression equations in order to estimate the dimensions of the distal part of the femur (mm) by the morphometry of the proximal part of the femur and femur length: All variables will be taken into account in millimeters.

D1= 1.603 + (0.468 x P1) + (0.803 x P5) + (0.504 x P12) – (0.803 x P14) + (0.461 x P15)

Adjusted R^2= 0.571, Standard Error of the Estimate= 2.859

D2= 61.031 x (1.399 x P1) + (0.604 x P2) – (1.126 x P5) – (0.804 x P8) + (0.329 x P11) + (0.490 x P13) – (0.353 x P14) + (0.832 x P15)

Adjusted R^2= 0.712, Standard Error of the Estimate= 2.443

D3= 48.895 + (0.895 x P1) – (0.181 x P9) + (0.193 x P11) – (0.380 x P14) + (0.518 x P15)

Adjusted R^2= 0.780, Standard Error of the Estimate= 1.851

D4= 39.033 + (0.225 x P2) – (0.143 x P3) – (0.238 x P5) + (0.170 x P7) – (0.258 x P9) – (0.168 x P10) + (0.378 x P11) + (0.159 x P12) + (0.138 x P14) + (0.396 x P16)

Adjusted R^2= 0.755, Standard Error of the Estimate= 1.422

D5= -2.628 + (1.794 x P1) – (0.404 x P2) – (0.575 x P5) – (0.198 x P11) – (0.495 x P14) + (0.393 x P15)

Adjusted R^2= 0.526, Standard Error of the Estimate= 1.998

D6= 15.168 – (0.434 x P1) + (0.216 x P2) + (0.073 x P8) – (0.078 x P9) + (0.009 x P11) + (0.109 x P12) – (0.377 x P13) + (0.217 x P14) + (0.020 x P16)

Adjusted R^2= 0.452, Standard Error of the Estimate= 0.818

D7= 17.549 + (0 .796 x P1) – (0.240 x P2) – (0.150 P7) – (0.157 x P12) – (0.290 x P13)

Adjusted R^2= 0.191, Standard Error of the Estimate= 1.956

D8= 28.587 + (0.139 x P1) + (0.261 x P2) – (0.481 x P5) – (0.174 x P8) + (0.087 x P12) + (0.145 x P14) + (0.185 x P15) + (0.061 x P16)

Adjusted R^2= 0.184, Standard Error of the Estimate= 1.251

D9= 38.046 + (0.394 x P1) + (0.757 x P2) – (0.835 x P5) – (0.566 x P8) + (0.317 x P12) + (0.450 x P13) + (0.591 x P15)

Adjusted R^2= 0.611, Standard Error of the Estimate= 2.298

D10= 11.405 + 0.,434 x P1) + (0.350 x P2) – (0.407 x P5) – (0.104 x P11) + (0.241 x P12) + (0.210 x P15)

Adjusted R^2= 0.678, Standard Error of the Estimate= 1.451

D11= 48. 388 + (1.672 x P1) – (0.468 x P4) – (0.988 x P5) + (0.306 x P6) – (0.282 x P9) – (0.254 x P10) + (0.498 x P11) – (0.660 x P13) + (0.253 x P14) +(0.521 x P16)

Adjusted R^2= 0.729, Standard Error of the Estimate= 2.202

D12= 27.916 + (1.162 x P1) – (0.259 x P2) + (0.230 x P4) + (0.111 x P7) – (0.267 x P8) – (0.126 x P9) + (0.114 x P10) – (0.153 x P12) + (0.687 x P13) – (0.394 x P14) + (0.522 x P15)

Adjusted R^2= 0.687, Standard Error of the Estimate= 1.802

D13= 9.193 + (1.246 x P1) + (0.270 x P2) – (0.163 x P3) – (0.173 x P4) – (0.256 x P5) + (0.223 x P8) – (0.172 x P9) + (0.145 x P11) – (0.280 x P13) + (0.283 x P15) + (0.212)

Adjusted R^2= 0.850, Standard Error of the Estimate= 1.305

D14= 49.726 – (1.223 x P1) – (0.432 x P2) + (0.747 x P5) – (0.341 x P6) – (0.111 x P7) + (0.339 x P8) + (0.251 x P13) – (0.119 x P14) – (0.193 x P16)

Adjusted R^2= 0.620, Standard Error of the Estimate= 1.676

D15= 18.316 + (1.738 x P1) – (1.190 x P2) + (0.371 x P3) – (0.896 x P6) – (1.153 x P14) + (0.599 x P15)

Adjusted R^2= 0.080, Standard Error of the Estimate= 5.492

D16= 57.322 – (0.861 x P1) – (0.467 x P3) + (0.52

3 x P4) + (0.198 x P14) + (0.305 x P15) – (0.263 x P16)

Adjusted R^2= 0.738, Standard Error of the Estimate= 1.674

DISCUSSION

The morphometric features of distal and proximal parts of the femur, the longest bone of the human body, have been investigated for applications in orthopedics and forensic anthropology based on the differentiation of the populations and genders[13]. The femur can be exposed to various inflammatory, degenerative, neoplastic, and traumatic processes due to its anatomical structure, location in the human body, and function. Comprehensive knowledge of anatomy regarding the morphometric features and dimensions of the femur is required for the proper management of the treatment and surgical planning of femoral diseases[8,14].

The alignment of the bones in the joints of the lower extremities can cause acute and chronic lower extremity injuries. It has been suggested that biomechanical changes that may result from abnormal alignment may cause changes in neuromuscular function and control of the lower extremity. To accurately define the relationship between the anatomical alignment and the risk of injury to the lower extremity, it is necessary to consider the alignment of the entire lower extremity instead of a single segment[15].

Correct selection of the prosthesis, correct sizing, and correct placement of joint components are important for the success of knee arthroplasty[16]. Geometric harmony between the prosthesis and the resected surface of the knee is critical for the long-term success of total knee arthroplasty[10]. Proper orientation of the femoral head and neck is necessary for the biomechanical function of the hip joint[7]. Operations on the femur are among the most common orthopedic applications. Variations in hip morphology and patient-specific consideration of hip morphology, design of implants, and other structures are very important in surgical planning[3]. Proximal femoral anatomy is a prerequisite for understanding the mechanics of the hip joint[17].

The long bones that contribute the most to a person's stature are the lower extremity bones, including the femur. For this reason, the femur is frequently used for stature estimation in identification in anthropology and forensic medicine applications. Various formulas have also been developed for the estimation of the total length of fractured and fragmented long bones[18,19]. In total hip arthroplasty, the design of the femoral component and the dimensions of the proximal part of the femur must be compatible with each other. Otherwise, the possibility of hip dislocations and implant fractures will occur[20].

Isaac et al.[17] studied in South Africa about femoral neck-shaft angle and they found the result with a mean of 126.7^o. In the study of Mahaisavariya et al.[21] in Thailand, they found the neck-shaft angle 128.04^o. Vaishnani et al.[22] studied investigated the neck-shaft angle in India and they found the neck-shaft angle 137.2 ± 5.1^o. İyem et al.[23] found the neck-shaft angle as 130.4 ± 5.1^o in Turkey. Yoshioka et al.[24] observed the femur-shaft angle 131^o in Canada. In the current study we obtained the femur neck-shaft angle as 134.11 ± 6.25^o in Turkey (Table 8).

As the results of the study of Vaishnani et al.[22] in India the femur length was found as 435.8 ± 27.32 mm. Verma et. al.[25] conducted their study in India and they found the femur length as 428.2 mm. Vinay et al.[20] studied in Telangana and they measured the average length of the femur as 433.3 mm. Ziylan et al.[26] found the maximum femur length as 428.4 ± 24.9 mm in left and 416.8 ± 6 mm in right femurs in Central Anatolia. According to the results of our current study, the entire femur length was ranged between 324.95 mm and 475.32 mm and the average was 400.27 ± 39.15 mm.

Verma et al.[25] found the femur head diameter 42.32±4.11 mm, femur neck length 44.75±8, femur neck diameter 33.02±4.22 mm in India. Unnanuntana et al.[27] studied on African-American and Caucasian femurs and they obtained the femur head diameter as 52.09±4.43 mm. Lin et al.[28] evaluated the proximal femoral morphometry in Taiwan and they found the femur head diameter 45.40 ± 3.21 mm. Umer et al.[29] measured the femur head diameter as 50.1±3.8 mm in the Pakistani population. Kamath et al.[30] observed the femoral head diameter as 44.80 ± 4.20 in the South-West Coast of the Indian population. De Sousa at al.[31] conducted their study on the Brazilian population and they obtained the femoral head diameter 31.1 ± 2.7 mm and 30.8 ± 3.0 mm, femoral neck length 30.1 ± 4.3 mm and 30.5 ± 4.1mm, femoral axis length 98.2 ± 5.9 mm and 97.4 ± 7.13 mm and femoral neck width 30.96 ± 2.94 mm. In the current study, we found the maximum vertical diameter of the femur head as 45,46 ± 3.02 mm, the diameter of the femur neck as 32.82 ± 3.37 mm, and the length of the femur neck as 44.22 ± 4.62 mm similar to Verma et al.[25]'s results. Also, we found the femoral neck axis length 94.26 ± 5.82 mm.

In order to obtain a successful surgical result from total knee arthroplasty, correct mechanical alignment between the bones, optimal bone removal, and soft-tissue balance are required. Knowing the anatomy of the surface areas of the bones removed for total knee arthroplasty is important to understand bone prosthesis compatibility and to develop ideal prosthesis designs[32].

As the result of the study of Murshed et al.[33] in which they evaluated the distal femur in Turkey, they found the maximal transverse width of intercondylar notch 19.9±2.3 mm in left and 20.4±2.7 mm in right; the maximal height of the intercondylar notch 30.8±3.4 mm in left and 31.4±3.4 mm in right, the epicondylar width of the femur 78.2±6.4 in left and 79.2±8.7in right, the lateral condylar width of the femur 24.9±3.3 in left and 24.9±2.8 in right, the medial condylar width of the femur 24.9±2.9 in left and 25.8±2.4 in right.

Phombut et al.[13] studied in Thailand population and they obtained the transepicondylar axis length 79.53 ± 6.54mm, the intercondylar notch width 20.06 ± 2.72 mm, the lateral condyle width 24.62 ± 2.78 mm, the medial condyle width 25.58 ± 2.56 mm, the lateral posterior condyle height 37.10 ± 2.96 mm, the medial posterior condyle height 38.66 ± 3.26 mm. Magetsari et al.[16] investigated the distal femur in India and they reported the femoral medio-lateral length, 65.98±6.51 mm, femoral medial antero-posterior length 42.56±5.58 mm, femoral lateral antero-posterior length 42.13±6.09 mm. Terzidis et al.[34] studied in Greece and they found the femur bicondylar width 83.9 mm, the femur intercondylar width 20.5 mm, the femur intercondylar depth 25.9 mm.

Femoral anteversion occurs when the anteversion angle exceeds 20^o in conditions such as cerebral palsy, developmental dysplasia of the hip, Perthes disease, or idiopathic excessive antetorsion[35]. Increased femoral anteversion angle and coxa valga cause an introverted gait and hip irregularity. Osteotomy is commonly performed to treat these problems. Femoral anteversion and femoral neck-shaft angles are important for surgical procedures such as osteotomy. Accurate and reliable measurement of these angles is necessary to obtain a good surgical outcome[36].

Mahaisavariya et al.[21] reported the anteversion angle as 11.37 ± 7.65° in their study conducted in Thailand. Kafa et al.[37] found the declination angle 16.59 ± 1.04° for contemporary femurs and 19.68 ± 1.89° for the femurs belonging to the Byzantine era in Turkey. Siwach[38] studied on Indian femurs and he declared the angle of anteversion as 13.68 ± 7.92°. In our study we found the transcondylar axis length 78.37 ± 5.49 mm, the medial posterior condyle width 27.83 ± 2.37 mm, the lateral posterior condyle width 26.77 ± 1.54 mm, the intercondylar notch width 18.61 ± 2.67 mm, the intercondylar notch depth 23.23 ± 5.22 mm and the angle of femoral neck anteversion (declination angle) 17.28 ± 7.53°.

The human body has a complex but harmonious structure. Therefore, it has been proven that the anatomical structure of the proximal part of the femur is effective on the morphology and biomechanical properties of the more distal parts of the lower extremity[39].

As a conclusion, knowing the anatomy of the femur as a whole and the correlations between the proximal and distal parts of the femur is very important for orthopedics, implant and prosthesis designers, forensic scientists, and anthropologists. The anatomical formations in the entire femur have a perfect harmony in accordance with the person's own anatomical structure. Therefore, in the total femoral prosthesis, just as other parts of the body should be taken into consideration, the proportional and correlative relationship of the femur should be considered in designs related to the proximal or distal femur. With the regression formulas we have developed, we believe that better surgical results can be obtained with a well-designed prosthesis and that it can make a great contribution to the patient's survival. In addition, with the regression formula, we have developed to be used in the methods applied in the identification of unidentified individuals, the entire stature of a fractured or fragmented femur that cannot be provided as a whole can be estimated, and the person's height can be obtained.

The limitations of the current study were the low number of bones, the unknown gender and age of the bones, and unknown historical age of the bones.

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