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Sex determination of proximal and distal end of femur on radiological images

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Abstract

The femur is one of the most commonly recovered bones in mass casualty disasters and is often used for identification, both for height and sex. However, in most cases the femur cannot be obtained as a whole. Therefore, this study evaluated and compared the reliability of sex estimates based on measurements taken from the proximal and distal ends of the femur. The study was conducted by evaluating the measurements of 225 femurs on radiological images obtained from a total of 128 individuals (67 males and 61 females). All the radiological images were obtained from the archive of the Radiology Department of Baskent University nine of the anthropometric measurements were linear and two were angular. When the anthropometric measurements obtained from the whole sample were evaluated in terms of differences between the right and left sides, significant differences were observed between the sides in terms of intercondylar angle, intertrochanteric distance (bc), inclination angle (inc), and femoral head width (b - b). On the other hand, as a result of statistical analyses performed to predict sex, significant differences were found between both sexes in all measurements except intercondylar angle and inclination angle. Logistic regression analysis was performed and a formula was developed to determine sex with the data obtained. A ROC analysis was performed to determine the discriminability threshold of the measurements taken from the distal and proximal ends of the femur for sex estimation. The findings show that transverse head diameter (E-E), femur length (C-C), femoral head width (A-A), and femoral neck width (B-B) measurements are reliable parameters with an accuracy rate of 97.0%, 94.6%, 93.5%, 91.6%, respectively, and the epicondylar width taken from the distal end is the most reliable parameter with an accuracy rate of 98.1%. A LOOCV (confusion matrix) was performed on all measurements and the validated model was found to be 91% successful in predicting sex according to logistic regression analysis.

Introduction

Identification of the victims is the major problem in forensic cases, especially in mass disasters such as earth quakes, fires, plane crashes or terrorist attacks, where great amount of people had been killed. Reliability of the identification in such cases is not only important for the legal procedures, but for the emotional wellbeing of the victims' families as well. During the identification process, the forensic anthropologists try to reach a conclusion by considering age, sex, height, ethnic origin, and characteristic morphological features of the individual (İşcan, 2001). For the isolated forensic cases the cause and the time of death, trauma findings also play an important role. Although DNA analysis is the gold standard for identification processes, anthropometric techniques allows rapid, inexpensive, and direct analysis of the remnants (Knecht et al., 2023). However, during identification process not only the anthropometric measurements, but the non-metric characteristics of the individual should also be evaluated (Burns, 2015).

However, only isolated bones can be obtained in both anthropological excavations and forensic cases. The femur is one of the most robust bones in the human skeleton, especially the proximal and distal ends, which are often recovered with little damage or intact (Kalaiyarasan et al., 2020). Femur is the commonly used bone to predict sex, alongside pelvis and cranium because of its robustness and strength. It could hardly be damaged due to environmental effects and keeps its morphological structure for a long time. In addition, it is generally present in a crime scene (Osorio et al., 2012; Gulhan et al., 2015). However, it is not always possible to obtain the bones intact, especially in mass disasters. When compared with the rest of the bone, proximal femur is often well preserved due to its high concentration of cortical bone (Rattanachet, 2022). Proximal femur also articulates with acetabulum and is a site of muscular attachments those may affect the morphological structure of the bone. On the other hand, in the cases of fire those may cause fragmentation due to thermal alterations, proximal femora will normally be preserved since it is enclosed large muscular tissues leaving them unburned or least affected by fire (Rattanachet, 2022). Proximal femur is also used to differentiate between human and non-human origins. For example, the third trochanter is commonly observed in quadrupedal animals, are the longer femoral necks of human beings when compared with the four-legged animals. However, in the cases where the remains are badly preserved or fragmentary, especially if the proximal part of the femur that is recognized as one of the best sex estimator is absent measurements form the distal part of femur, especially bi-condylar breadth could be used for the prediction of sex (İşcan, 1984; King et al., 1998; Trancho et al., 1997). However, morphological features of the bones cannot be applied cross all populations since some characteristics are not apparent or could be less identifiable in some of them (Albanese et al., 2008). Instead of evaluating the morphological characteristics quantitative analyses enables more objective and are less prone to human errors. In the studies on sex prediction it is reported that breadth and circumference measurements give more reliable estimates rather than length measurements (Alunni et. al., 2008; Steyn and İşcan, 1997; DiBennardo and Taylor, 1979). For instance, Purkait (2003) in her study emphasized the importance of vertical diameter of femoral head to distinguish between male and female individuals since it is the major component of femur supporting relatively heavier body weight of males.

It is known that the heritable transmission of the anthropometric characteristics and dimensions causes phenotypic differences in populations (Robinson and Bidmos, 2011). However specific details may be caused by bone adaptation to its environment (Chatterjee et al., 2020). Racial differences described in the works of various authors, especially on the dimensions of the proximal segments of the femur (Lavelle, 1974), indicates the need of population specific formulae for more accurate predictions of sex. The aim of the present study is to calculate formulae for estimating sex depending on the anthropometric measurements from the proximal and distal parts of femur for the Anatolian population.

Parsons (1714), Ingalls (1924), and Pearson and Bell (1919) were the first to study long bones and did important work on sex differentiation. These early studies provided an important foundation for the study of sexual dimorphism (Van, 1972). The advantage of these studies lies in the statistical analysis of metric observations. However, the focus remained entirely on measures of variation between the sexes (Brooks and Warlde, 1962). On this basis, Parsons considered four measurements of the femur to be of primary importance in determining sex: femoral head diameter, maximum femoral length, epicondylar width, and maximum antero-posterior thickness of the diaphysis (Choi and Trotter, 1970). In addition, Parsons calculated two index values: femoral length-head diameter and diaphyseal thickness and epicondylar width (Van, 1972). Most of these studies were conducted on well-preserved skeletons of known age and sex. Ethnicity determination based on morphological characteristics of the femur was studied by Stewart (1962). Black (1978) used the mid-shaft circumference of the femur in simple skeletal studies, which aided in sex estimation. DiBennardo and Taylor (1982) also made this method useful.

The pelvis is highly susceptible to damage in an anthropological context. That is why different formulae had been calculated for sex estimation based on various bones including long bones such as femur (Alunni et al., 2008; Curate et al., 2016; Curate et al., 2017), tibia (Steyn and İşcan, 1997), humerus (Atamtürk et al., 2010; Albanese, 2013; Tallman and Blanton, 2020), radius (Jongmuenwai et al., 2021; Nogueira et al., 2023) or ulna (Purkait, 2001; Cowal and Pastor, 2008; Srivastava et al., 2013). In some of the studies formulae were calculated depending on the combination of these bones (Steyn and İşcan, 1997; Bidmos and Mazengenya, 2021), and it was reported that sex could be estimated by these formulae with a reliability changing between 70 to 93% (Knecht et al., 2023). However, formulae calculated depending on the measurements taken from postcranial bones other than pelvis achieve more variable classification rates (Attia et al., 2022). Both taphonomic factors and poor recovery techniques can lead to loss of information (Upadhyay and Mishra, 2021). In contrast, the femur is a much more robust bone and more resistant to damage. Some studies have linked bipedal locomotion to the femur and directly to the pelvis (Lovejoy, 2005). However, the widening of the diameter of the birth canal to successfully deliver large-brained babies and the evolutionary process have led to morphometric differences in the proximal end of the femur (Bramble and Lieberman, 2004). The evolutionary change between the pelvis and femur in females can be seen in the angle and length of the femoral neck. All of these studies increase the importance of measurements from the proximal end of the femur (Albanese et al., 2008).

Estimation of sex is the essential step in the identification of skeletal remains since it narrows down the possible matches of missing person (Curate et al., 2017). In general, men are taller than women, have more robust skulls, facial features, and its well-known that bones of male individuals are thicker and coarser with more prominent indentations and protrusions at the edges and corners when compared with those of females (Stewart, 1947). In general, it is known that men are taller than women, have more robust skulls, facial features, greater muscle strength, and speed. However, it is a fact that the differences between men and women start to decrease when factors such as environmental conditions and nutrition are taken into consideration (Frayer and Wolpoff, 1985). Most of these differences result from hormonal events occurring during puberty (Beach, 1981). Women store more subcutaneous fat, while men have proportionally more muscle fibers; pre- and postnatal hormonal levels and growth rates differ (Glucksmann, 1981). In terms of male and female genetics, despite extensive phenotypic differences between the sexes, males and females are genetically almost identical. In most other species, the male and female genomes differ by a few genes on sex-specific chromosomes, such as the Y chromosome in mammals (Ellegren and Parsch, 2007). This implies that the vast majority of differences are due to the differential expression of genes found in both sexes (Connallon and Knowles, 2005).

The areas where differences between the sexes are most noticeable are the skull and pelvis, primarily due to birth adaptation. Therefore, morphological and morphometric differences can be observed in the angle of the femur articulating with the coxae, the length, and the area where the epiphysis fuses (Bramble and Lieberman, 2004). In light of this information, our hypothesis is that we aim to determine sex by evaluating differences resulting from measurements taken from the distal and proximal ends of the femur. Simultaneously, we aim to enhance the reliability of studies conducted on skeletal materials with the support of radiographic images. Anthropometric differences observed between the sexes significantly vary between populations. This study will be able to contribute to many forensic fields such as virtual autopsy. Also skeletal fragments are not always obtained as a whole, so in cases where the skeleton is incomplete, obtaining the femur and making measurements from the intact dorsal or proximal part of the femur will substantially contribute to evaluating the reliability of such measurements in determining sex and its applicability in forensic cases, aligning with other studies in the literature.

Materials and method

Ethical approval

This study was approved by Başkent University (Ankara, Turkey) Medical and Health Sciences Research Board approved (Project no: KA21/43) and supported by Başkent University Research Fund.

Participants and study design

The study was performed by evaluating the measurements of 225 femurs. Anonymized radiological images of 128 individuals, 67 males and 61 females, aged between 24 and 82 years, were obtained from the archive of the Radiology Department of Başkent University Hospital, Ankara, Turkey.

Measurements

CT examinations were performed on a 16-detector multi-slice CT (Emotion 16, Siemens, Erlangen, Germany), lower extremity CT angiograms or whole body CT scans of the bony structure obtained as thin slices between 2020 and 2022 were retrospectively measured by multiplanar reformat (using syngo software version VB60A_HF04 (Siemens Healthineers, Forchheim, Germany). Patients were taken in supine position. Multiplanar reformat images were created on axial sections. Any deformity or prosthesis in the measured parts of the femur were excluded from the study.

Forensic anthropologists often use morphological and metric methods to estimate the sex of human remains. The continuous increase in the use of imaging techniques in forensic anthropology research has facilitated the derivation and revision of existing population data. Geometric morphometric (GM) method and Diagnose Sexuelle Probabiliste (DSP) method are emerging as valid methods and widely used techniques in forensic anthropology in terms of accuracy and reliability (Krishan et al., 2016). It is well known that longitudinal measurements such as the length of the bones are not discriminative as width and circumference measurements (Klales, 2013; İşcan et al., 1998). For instance, İşcan and Ding stated that epicondylar width is one of the most discriminative character alone for estimating sex, and this suggestion had been supported by various authors (Spradley and Jantz, 2011; Purkait et al., 2004). In the present study the measurements those are clearly visible on radiological images are preferred to be used depending on literature knowledge (Colman et al., 2017)

Distal end measurements in axial plane (Fig. 1)

- a- Distance between medial and lateral epicondyles (EAM): Epicondylar width (distance between the outermost points of the medial lateral epicondyles of the femur in the axial plane)
- b- Medial and lateral intercondylar width (ICW): Intercondylar width (measurement at the widest part of the intercondylar notch at the distal notch of the femur in the axial plane).
- c- Intercondylar depth (ICD): Intercondylar depth (the length of the perpendicular line drawn from the line parallel to the posterior border of both condyles to the deepest point of the intercondylar notch in the distal part of the femur in the axial plane).
- d- Intercondylar angle (ICA): Intercondylar angle (the angle between two lines drawn from the deepest part of the intercondylar notch in the distal part of the femur in the axial plane through the inner edge of both condyles).

Proximal end measurements in the vertical plane (Fig. 2)

- e- Femoral head width (AA): Maximum rectilinear vertical femoral head diameter measured perpendicular to the neck axis.
- f- Femoral neck width (BB): Minimum rectilinear cranio-caudal diameter of the neck, measured in the vertical plane.
- g- Intertrochanteric distance (BC): Distance between the most prominent points of the greater trochanter and lesser trochanter.
- h- Femoral inclination angle (collodiaphyseal angle) (INK)

Proximal end measurements in the axial plane plane (Fig. 3)

- i- Femur length (CC): The distance between the innermost edge of the femoral head and the outermost edge of the trochanter major in axial plane through the femoral neck and femoral head
- j- Transverse head diameter (EE): The widest diameter of the femoral head in the anteroposterior direction in the axial plane created to pass through the femoral neck and the femoral head.
- k- Transverse neck diameter (GG): Rectilinear antero-posterior diameter of the femoral neck at the level of and perpendicular to the vertical neck diameter.

Data analysis

The Kolmogorov-Smirnov normality test was used to test the compatibility of quantitative variables with a normal distribution, and mean ± standard deviation values were used as descriptive statistics for variables that fit a normal distribution, and median values were used for variables that were not normally distributed. Independent 2-sample t-test and Mann-Whitney U test were used to compare measures by sex. Paired t-test and Wilcoxon test were used to compare right and left side measures. Univariate logistic regression analysis was first used to determine the variables that could be used to determine sex, and variables with $p<0.10$ were included in the multiple analysis. The Enter method was used as the variable selection method in the multiple models. Cronbach's alpha and ICCs (intraclass correlation coefficients) were used

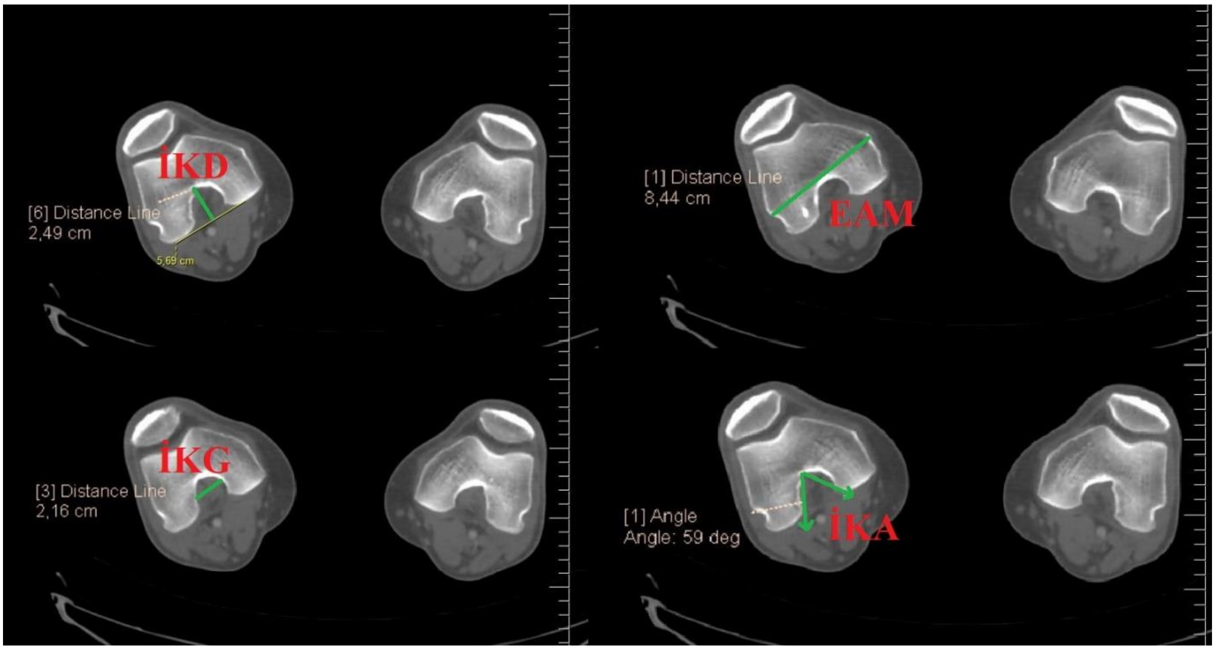

Figure 1: Distal end measurements in axial plane

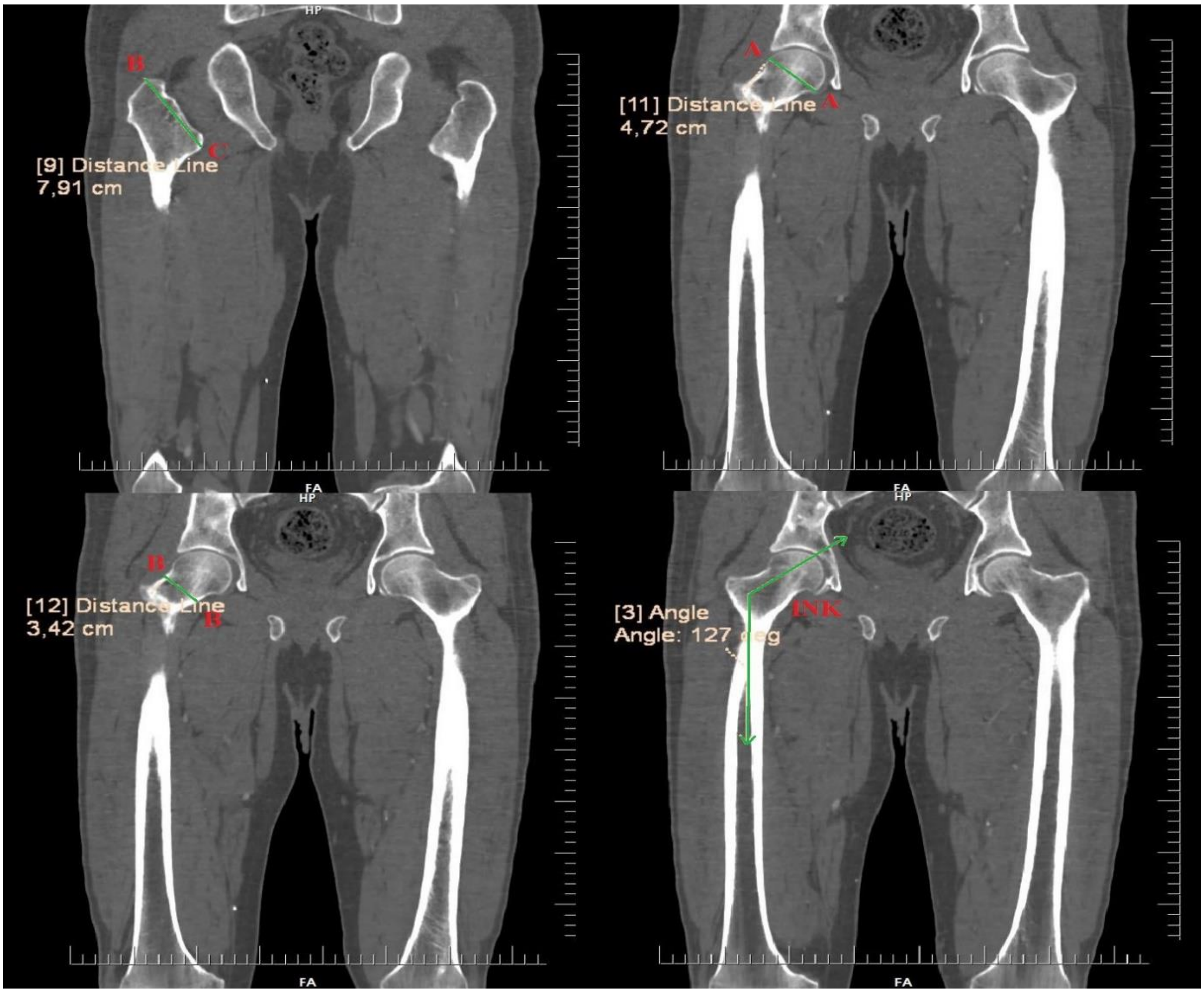

Figure 2: Proximal end measurements in the vertical plane

Figure 3: Proximal end measurements in the axial plane

for reliability analysis. In all hypothesis tests, the probability of Type I error was set at α = 0.05, and statistical evaluations were performed using the SPSS v25.0 package program.

In this study, a data set of a total of 225 specimens, including right and left, of 128 individuals (67 males and 61 females), including 9 linear and 2 angular anthropometric attributes, were classified with logistical regression analysis using machine learning techniques to create a model that best determines the sex. The data set is randomly divided into training and test sets. Following the training process with the logistic regression method, the complexity matrix and roc curve were obtained with a test set. 5-fold CV, 10-fold CV and LOOCV methods were used for validation. The results of cross-verification methods are very similar and LOOCV results have been. The classification success of the obtained model was measured by sensitivity, selectivity, precision, memorization, accuracy and F1 scores. The model was created and tested using the R Studio programming language.

In all measurements, no directional distinction was made in the analysis, as the right and left measurement results showed similarity by sex. For example, 225 is 116 males (57 left, 59 right) 109 females (54 left, 55 right). The data set containing femur proximal and distal findings was classified using a logistic regression model with 44 examples, accounting for a total of 225 for example 20%. The model resulted in a complexity matrix, and accuracy, sensitivity, selectivity, recall, precision, and F1 scores were obtained. These values were obtained for LOOCV because the results of 5-fold CV, 10-fold CV and LOOCv cross-validation (CV) methods were very similar.

When all variables are in the model, the Akaike information criterion is 54.064, while the EAM and EE measurements are significant. To a better model, the model was reduced to EAM, ICW, ICD, BC and EE, and the model's AIC score was 40.538. No improvement was observed in the size of the model when any variables were removed from the model.

Results

The average age of male and female respondents is close to each other. Therefore, we did not consider the age factor when estimating sex (Table 1). The mean age of women was 61.81±11.26 years, while the mean age of men was 62.57±13.19 years (*P* = 0.736).

Table 1: Age (year) measurements by sex

	Female		Male	
Age (year)	61.81±11.26	65 (35-79)	62.57±13.19	63 (21-89)

Table 2: Intraclass correlation coefficient

ICC	Comments*
ρ < 0.4	Weak level of compliance
0.4 < ρ < 0.59	Moderate compliance
0.6 < ρ < 0.74	Good level of compliance
ρ > 0.75	Perfect compliance

*Cicchetti (1994).

Table 3: Accuracy of measurements taken from the distal and proximal end of the femur

	Intraclass correlation	95% Confidence interval		Sig.
		Lower bound	Upper bound	
EAM	0.841	0.642	0.934	**<0.001**
IKG	0.789	0.541	0.911	**<0.001**
IKD	0.932	0.836	0.972	**<0.001**
IKA	0.839	0.638	0.933	**<0.001**
BC	0.979	0.949	0.992	**<0.001**
INK Angle	0.833	0.625	0.930	**<0.001**
A-A	0.761	0.489	0.898	**<0.001**
B-B	0.896	0.757	0.958	**<0.001**
C-C	0.977	0.943	0.991	**<0.001**
E-E	0.841	0.642	0.934	**<0.001**
G-G	0.840	0.640	0.933	**<0.001**
Epiphysis	0.861	0.682	0.942	**<0.001**
Head length	0.882	0.726	0.951	**<0.001**

Intraclass correlation coefficient

Table 4: Comparison of all measurements by sex, regardless of direction

	Female (n=61)	Male (n=67)	*P*
Age	57 (21-81)	63 (21-89)	0.486
A-A	42 (38-49)	47 (42-53)	<0.001*
B-B	27 (22-38)	32 (27-39)	<0.001*
C-C	87 (79-106)	100 (86-114)	<0.001*
E-E	43 (38-48)	48 (43-96)	<0.001*
G-G	23 (19-31)	26 (20-32)	<0.001*
INK	123.30±5.75	123.78±5.59	0.532
B-C	66 (55-79)	76 (46-90)	<0.001*
EAM	72.86±3.11	83±3.70	<0.001*
ICA	53.92±5.54	55.34±5.76	0.061
ICD	24 (20-30)	27 (22-34)	<0.001*
ICW	20 (15-25)	23 (18-28)	<0.001*

$^*P < 0.05$

An intra-class correlation coefficient was used to determine the consistency of measurements taken from the femur distal and proximal ends. The observer's harmonization was examined using a two-way random-effect model. Conditions where the *P*-value was below 0.05 were evaluated as statistically significant results. ICC (intraclass correlation coefficient) methods were used for reliability analysis. ICC is a statistical method that measures the consistency and repeatability between measurements. It takes a value between 0 and 1, and the closer to 1, the more consistent the measurements are. An ICC value of 0.75 and above is considered high reliability. In our tables, the ICC values of our measurements range from 0.76 to 0.97. Since all of our measurements have perfect ICC values, the measurements are reliable (Table 2 and 3).

Intercondullary angle and inclination angle values did not show a significant difference between male and female subjects (*P*>0.05), while all other measurements were significantly higher in male subjects compared to females (*P*<0.001) (Table 4).

The results of the analysis of the comparison of the anthropometric measurements taken from the right and left side for the whole sample without sex discrimination are presented. No significant differences were observed between the two sides, except for the intercondylar angle, the intertrochanteric distance (bc), the inclination angle (inc), and the width of the femoral neck (b - b). The intercondylar angle (*P*<0.05) and the intertrochanteric distance (*P*<0.001) were higher on the right side, while the inclination angle (p<0.001) and the width of the femoral neck (b - b) (*P*<0.05) were higher on the left side. When the distal measurement parameters were examined, no significant difference was found between the right and left femur measurements and parameters (*P*>0.05). That is, the distal distances between the distal ends of the right and left femurs were similar and there was no statistically significant difference. Based on these results, it can be said that the right and left femurs have similar characteristics in the distal end region (Table 5).

When comparing the right and left sides in terms of sex, the angle of inclination (0.001) and the width of the femoral head (0.05) in females show a significant difference between the two sides, while the width of the femoral neck (0.05) in males shows a significant difference between the two sides. Intertrochanteric distance was significantly different between right and left side in both sexes (Table 6).

Table 5: Comparison of right and left measurements (n=225)

Measurement variables	Mean ± SS	Median (Min-Max)	*P*
R_EAM L_EAM	78.01±6.04 77.92±6.07	78 (66-93) 77 (67-92)	0.795[b]
R_ICW R_ICW	21.19±2.50 21.69±6.50	21 (15-26) 21 (16-83)	0.472[b]
R_ICD L_ICD	25.94±2.39 25.92±2.39	26 (22-33) 26 (21-33)	0.683[b]
R_ICA L_ICA	55.07±5.70 53.90±6.04	55 (43-67) 54 (26-66)	**0.020[a]**
R_BC L_BC	72.17±7.92 70.33±7.87	72 (46-90) 70 (47-89)	**<0.001[a]**
R_INK ANGLE L_INK ANGLE	121.99±5.14 124.65±7.48	122 (111-134) 125 (77-140)	**<0.001[a]**
R_A-A L_A-A	44.97±3.36 45.99±8.33	44 (39-52) 45 (38-124)	0.062[b]
R_B-B L_B-B	29.64±3.16 30.26±3.51	30 (22-37) 30 (23-46)	**0.008[b]**
C-C L_C-C	93.93±7.88 93.33±9.58	93 (80-114) 92 (36-114)	0.920[b]
E-E L_E-E	45.74±3.40 46.53±7.86	45 (39-53) 45 (38-99)	0.692[b]
G-G L_G-G	24.79±2.85 24.78±3.37	24 (19-32) 24 (20-46)	0.468[b]

a: Paired t test, b: Wilcoxon sign test

Table 6: Comparison of right and left measurements in sex groups

Measurement variables	Female		*P*	Male		*P*
	Mean.±ss	Median (Min-Max)		Mean.±ss	Median (Min-Max)	
R_EAM	72.94±3.36	73 (66-83)	0.489[a]	82.8±3.58	82 (74-93)	0.747[a]
L_EAM	72.77±2.91	73 (67-80)		82.87±3.72	82.5 (74-92)	
R_ICW	19.71±2.29	20 (15-25)	0.931[b]	22.58±1.79	22 (18-26)	0.342[b]
L_ICW	19.71±2.14	19 (16-25)		23.56±8.45	23 (18-83)	
R_ICD	24.46±1.46	24 (22-28)	0.949[b]	27.35±2.25	27 (23-33)	0.607[b]
L_ICD	24.46±1.34	24.5 (21-27)		27.29±2.35	27 (22-33)	
R_ICA	54.44±5.62	54 (43-66)	0.066[a]	55.65±5.76	56 (44-67)	0.115[a]
L_ICA	53.42±5.22	53 (44-65)		54.35±6.74	55 (26-66)	
R_BC	67.08±5.10	67 (55-79)	**0.002[a]**	76.98±7.08	78 (46-90)	**<0.001[a]**
L_BC	65.71±5.59	66 (55-79)		74.78±7.17	75 (47-89)	
R_INK ANGLE	121.94±4.96	122 (111-131)	**<0.001[a]**	122.04±5.35	122 (111-134)	0.058[a]
L_INK ANGLE	124.87±6.17	125 (110-138)		124.45±8.6	125 (77-140)	
R_A-A	42.44±2.07	42 (39-49)	0.322[b]	47.36±2.47	47 (42-52)	0.114[b]
L_A-A	42.69±2.20	43 (38-49)		49.11±10.54	47 (43-124)	
R_B-B	27.46±2.42	27 (22-35)	0.266[b]	31.69±2.28	32 (27-37)	**0.007[b]**
L_B-B	27.88±2.34	28 (23-38)		32.51±2.9	32 (28-46)	
R_C-C	87.88±4.62	87 (80-106)	0.639[a]	99.64±5.77	100 (86-114)	0.292[a]
L_C-C	88.02±4.27	87.5 (79-101)		98.35±10.49	99 (36-114)	
R_E-E	42.98±1.80	43 (39-48)	0.115[b]	48.35±2.32	48 (44-53)	0.479[b]
L_E-E	42.73±1.79	43 (38-48)		50.13±9.55	48 (43-99)	
R_G-G	22.92±1.83	23 (19-28)	0.825[b]	26.55±2.5	26 (20-32)	0.442[b]
L_G-G	22.88±1.93	23 (20-31)		26.56±3.47	26 (21-46)	

a: Paired t test, b: Wilcoxon sign test

In the comparisons made according to sex, the intercondylar angle and inclination angle variables did not differ between the groups (P>0.05). The significant variables other than these variables were included in the multiple logistic model and roc analysis was performed.

ROC analysis was performed to determine a threshold for the discriminability of the distal and proximal femur measurements for sex prediction. The cut-off point with the highest sensitivity and selectivity was used to determine the threshold. The area under the curve is interpreted as excellent discrimination between 1.0-0.90, good between 0.90-0.80, fair between 0.80-0.70, poor between 0.70-0.60, and poor between 0.60-0.50. We aimed to determine a threshold for the discriminability of measurements from the distal and proximal ends of the femur in sex prediction. Here, high measurements from the distal and proximal ends of the femur indicate that the individual is male. Accordingly, the cut-off point with the highest sensitivity and selectivity for the A-A measurement is 45.5. When individuals with an A-A greater than 45.5 are diagnosed as male, the sensitivity of the A-A is 82.76% and the selectivity is 92.7%. The area under the ROC curve is 93.5%. Therefore, the discriminative power of the A-A variable is excellent. The 95% confidence interval for this area is 90.4%-96.6%. The obtained score was found to be statistically significant (p<0.001). It can be said that the discriminating power of the variables A-A, B-B, C-C and E-E is excellent, and the discriminating power of the variables G-G, BC, Intercondylar depth, Intercondylar width is good. The epicondylar width is the variable that gives the best results in differentiating sex. Then E-E, C-C, A-A and B-B are the variables with the highest power to determine sex. When individuals with an epicondular width measurement above 78.5 were diagnosed as male, sensitivity was 91.38%, selectivity 97.2% and area under the curve 98.1% (p<0.001; 95%CI (0.966;0.996) (Table 7).

Table 7: Threshold values for anthropometric measurements

Test result variable(s)	Area	Std. error[a]	Asymptotic Sig.[b]	Asymptotic 95% confidence interval Lower bound	Upper bound	Cutoff	Sensitivity	Specificity
A-A	0.935	0.016	**<0.001**	0.904	0.966	>45.5	%82.76	%92.7
B-B	0.916	0.019	**<0.001**	0.878	0.954	>29.5	%86.20	%81.7
C-C	0.946	0.015	**<0.001**	0.917	0.975	>92.5	%88.79	%89.0
E-E	0.970	0.009	**<0.001**	0.952	0.989	>44.5	%95.69	%88.1
G-G	0.884	0.023	**<0.001**	0.839	0.930	>24.5	%79.31	%87.2
BC	0.885	0.022	**<0.001**	0.841	0.928	>70.5	%81.03	%80.7
EAM	0.981	0.008	**<0.001**	0.966	0.996	>78.5	%91.38	%97.2
ICD	0.852	0.025	**<0.001**	0.802	0.902	>25.5	%81.90	%74.3
ICW	0.823	0.028	**<0.001**	0.769	0.877	>21.5	%70.69	%79.8

ROC Analysis

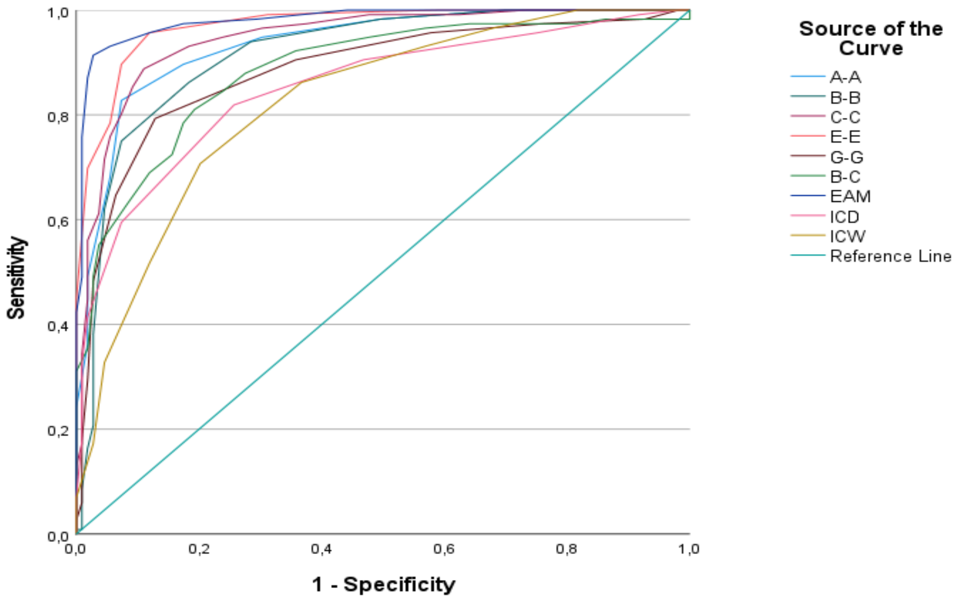

Fig 4: Areas under the curve (ROC) for anthropometric measurements

Table 8: Leave-one-out cross validation

	Reference	
Prediction	Female	Male
Female	19	2
Male	2	21

LOOCV	Accuracy (%95 CI)	Recall	Precision	NPD	F1 scor
Lojistik Regresyon	0.9091(0.7833, 0.9747)	0.913	0.913	0.9048	0.913

Epicondylar width, intercondylar width and EE measurements were significant in the model, while intercondylar depth and B-C measurements were very close to significance. Therefore, when asked to predict sex using these variables, the probability of correct classification was calculated as 91%. The results of this classification are given in the table below. The effect of epicondylar width variable on sex is significant. Accordingly, an increase of 1 unit in epicondylar distance increases the probability of the person being male by approximately 1.86 times (95%) (G.A 1.26-2.62, *P*=0.007). The effect of the intercondylar width variable on sex is significant. Accordingly, an increase of 1 unit in the depth of the intercondylar increases the probability of being male by approximately 1.85 times (95%) (G.A 1.06-4.01, *P*=0.048). The effect of E-E variable on sex is significant. Accordingly, a 1-unit increase in E-E increases the probability of a person being a man by approximately 2.14 times (95%) (G.A 1.22-3.82, *P*=0.012). The success of the data trained on the training data is classified on the test data set. The validated model has a correct classification rate of 0.91. A true positive detection rate of 91.3 percent and a true negative detection rate of 9.048 percent were obtained. The F1 score was calculated as 91.3%. As a result, the classification success of the validated model, i.e. its success in determining sex, is 91% according to logistic regression analysis. The ROC curve of the model and the area under the calculated curve is 0.965 and the classification success is high (Table 8, Fig. 5).

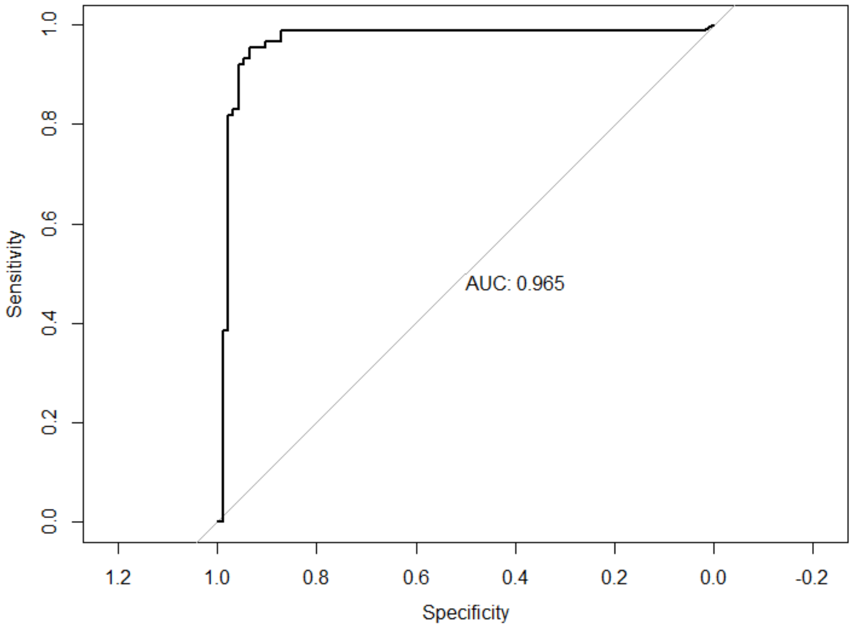

Figure 5: Model ROC curve with LOOCV cross validation

Discussion

Considering that the femur cannot always be obtained as a whole in both forensic cases and anthropological studies (Rattanachet, 2022), in this study we aimed to evaluate the reliability of measurements taken from the proximal and distal parts of the femur separately for sex prediction.

The rate of decomposition and skeletalization of the body depends on the depth of burial, soil type and environmental factors (Forbes, 2008; Janaway et al., 2009). Bone is a composite tissue and is composed of three main fractions: a protein fraction consisting mainly of collagen, which acts as a supportive scaffold; a mineral component consisting of hydroxyapatite for hardening, protein structure; and other organic compounds such as mucopolysaccharides and glycoproteins (Hare, 1988; Goffer, 2006; Janaway et al., 2009). Methods of skeletal extraction and errors in excavation can cause physical differences. In calcareous sand or loam, which is moist and has more oxygen, the bone surface will be rougher and may crack and warp after drying. On the other hand, bone buried in coarse calcareous gravel will lose a large amount of collagen and will have the consistency of powdered chalk (Goffer, 2006; Boddington et al., 1987). Bone chemistry and the sorption and desorption of metals in soil are highly controversial and have been the subject of numerous studies (Dent et al., 2004). There may be differences in the mass of bone according to humidity and temperature. Looking at living individuals and dry bones, differences in bone mass are observed and even humidity and temperature increase the rate of differences in bone mass (Delannoy et al., 2016). Looking at differences in mineral density, women tend to be less whole than men (Biehler-Gomez et al., 2022). Despite the inorganic and organic changes in the structure of bone, new methods need to be applied and existing methods need to be improved (de Froidmont et al., 2013). Female and male growth curves run extremely close until the feminine growth cessation. Significant differences between sexes appear after cessation of growth in female and they are due to the longer period of male growth (Cunningham et al., 2016). All parts of the skeleton are important, especially in cases where the individual is unrecognizable and the decay process has taken place. In this case, we have chosen the femur, one of the strongest and most robust bones in the skeletal system. For the studies on sex prediction to eliminate the deteriorations caused by decomposition of bones and some other natural effects radiological images can be accepted as the best from which mesurements can be taken, especially if there is a lack of skeleton collections with known age and sex. Since there is no skeletal colletion for Anatolian population we prefered to use anthropometric dimension taken from radiological immages in the present study. However, remnants available from crime scenes or from scene of a diaster are porobably decomposed of dammaged by natural effects. This could be accepted as a limitation of the study.

Burns (1987) developed several statistical methods for sexing skeletal remains. She emphasized that sex estimates based on femur measurements are highly reliable. Also in the present study it is suggested that measurements taken from the distal and proximal ends of the femur can yield very good estimates with reliabilty of 91%. Cavaignac et al. (2016) analyzed CT scans from 256 subjects living in the south of France and correctly identified 77.3% of cases with all measurements taken from the distal part of the femur. In general, distal measurements gave also better results in our study.

Khaleel and Shaik (2014) looked at the differences between the right and left femur in a study of 50 femurs; the right epicondylar width was 73.96 ± 4.99 mm and the left epicondylar width was 76.35 ± 7.0 mm. the inclination angle was 124.44 ± 5.7 mm and the left inclination angle was 126.3 ± 7.33 mm. Right transverse head diameter was 37.74 ± 3.05 mm and left transverse head diameter was 38.00 ± 3.13 mm. In our study, no significant differences were observed between the right and left measurements except for angular measurements, intertrochanteric distance and width of the femoral neck (Table 5). When we evaluated the right and left comparison in female femurs and the right and left comparison in male femurs separately, similar results were obtained (Table 6). In general, the difference between the angle measurements does not contribute to our study in terms of sex estimation. Because in this study, which we planned to make sex estimation, angular measurements did not show significant differences in men and women (Table 4). However, a significant difference was found between right and left measurements, independent of sex estimation. This emphasized that the inclination angle and intercondylar angle are not reliable parameters. Especially EAM, ICW, ICD, AA, CC, EE, GG measurements give reliable results in terms of sex estimation. In other words, when only the right femur or only the left femur is obtained, it shows that sex estimation can be made with these parameters. Because there is no significant difference between right and left measurements.

Gulhan et al. (2015) established discriminant function equations for Turkish population from the measurements taken on femur CT images, and the accuracy of the equations ranged between 63.5 to 88.0% with single variables. Stepwise analysis provided an accuracy of 91%. In another study Attia et al. (2022) evaluated the performance of machine learning in sex estimation depending on the dimensions of femur on the CT images of the proximal part of the femur available from Turkish and Egyptian patients epicondylar width, femoral vertical neck diameter and intertrochanteric diameter were found to be the most discriminating variables with an accuracy of 91%. In our study, epicondylar width (EAM), femoral vertical neck width (BB) and interthrocantaric distance (BC) gave reliable results of 98.1%, 91.6%, and 88.5%, respectively. Also in the present study machine learning in sex estimation from femur is evaluated and E-E, C-C, A–A measurements taken from the proximal end of the femur are reliable parameters with an accuracy rate of 97.0%, 94.6%, 93.5%, respectively, whereas epicondylar width taken from the distal end is the most reliable parameter with an accuracy rate of 98.1%.

Epicondylar width, intercondylar width and distal epiphysis width were measured in a study of 88 French male and female femur samples. The mean value of epicondylar width was greater in men than in women (84.3 mm vs 74.8 mm), confirming the sexual dimorphism of this parameter. Moreover, the results showed an accuracy rate of 95.4% in the sexing of individuals (Alunni et al., 2008). Similarly, Steyn and İşcan (1997) found that distal width parameters gave the best classification results in their study on African whites. Average accuracy rates ranged between 86% and 91%. In our study, intercondylar width gave a value of 82.3%. epicondylar width measurement was one of the most reliable parameters with an accuracy of 98.1%.

In most of the studies on sex estimation based on femur dimensions, it has been shown that width measurements, especially epicondylar width and intercondylar width show statistically significant differences between male and female individuals and it was also ephasised that both epicondylar and intercondylar distance are wider in males (Kim et al, 2013; Bellemans et al., 2010; Shelbourne et al., 2007). Giorgi (1956) stated in his studies that the narrowing of the intercondylar width may be congenital as well as sex related. Similar with the above mentioned studies width measurements in our study were significantly different between the sexes and greater in male individuals ICW 82.3% and EAM 98.1%.

Kim et al. (2013) studied the accuracy of intercondylar depth in sex estimation on 30 male and 30 female Koreans and obtained reliable results. Consistent with the findings of Kim et al., the intercondylar depth in our study showed a statistically significant difference between males and females intercondylar depth (85.2%) and classification success was obtained for the epicondylar width measurement (98.1%), which was the second highest value. However, Lombardo et al. (2005) reported no difference between males and females related with intercondylar depth.

When neck-shaft angles were evaluated related with sex estimation Kanchan et al. (2021) stated in their study that the angle of inclination is higher in men than in women, and this difference is statistically significant. On the other hand there are various authors emphasizing that there were no significant differences between male and female individuals relates with neck-shaft angles. Lofgren et al. (1956) found the angle of inclination to be 125.1 degrees in men and 125.2 degrees in women and stated that there is no significant difference between them. Reikeras et al. (1982) also found the angle of inclination to be 128.3 degrees in males and 127 degrees in females and also stated that there was no significant difference between the two sexes. Pujari (2013) also found no significant difference in the angle of inclination between males and females in a Sri Lankan population. Similarly, Ramezani et al. (2019) reported that femoral neck-shaft angles were compared for sex determination but no significant difference was found in the inclination angle. The angle of inclination in the present study was 123.78 for males and 123.30 for females, and no statistically significant difference was found between males and females. Therefore, it can easily be argued that the angle of inclination is not a reliable parameter for predicting sex.

In our study, logistic regression analysis based on measurements taken from the distal and proximal parts of the femur showed a high correct classification rate of 91% in sex prediction with measurements taken from the femur. On the other hand, angular measurements taken from the femur (intercondylar angle and inclination angle) cannot be considered as suitable parameters for sex prediction because they do not show a significant difference between males and females (Table 4). In our study, according to the results of ROC analysis, the epicondylar width from the distal end of the femur was the variable that gave the best results in differentiating sex with an accuracy rate of 98.1%. Other reliable measurements were E-E, C-C, A-A, B-B, and variables taken from the proximal end of the femur, which were found to have excellent discriminatory power (97.0, 94.6, 93.5, 91.6, respectively).

Steyn and İşcan (1997) used logistic regression analysis to develop a sex determination formula based on femoral measurements in a population of Bangladeshi adults, similar to our study. The authors found that the combination of five femoral measurements (femoral head circumference, femoral neck circumference, femoral neck width, intertrondylar distance, and medial condyle width) resulted in a correct classification rate of 91.2%. However, they did not evaluate measurements from the proximal and distal parts of the femur separately. Although many studies have suggested that femoral neck circumference and femoral head circumference are the most commonly used measurements for sex determination and have high reliability in predicting sex (Krogman and İşcan, 1986; Ousley and Jantz, 1998). In our study suggests that epicondylar width from the distal end of the femur yielded the best results.

Monum et al. (2017) stated in their study on a Thai population, epicondylar width was the best variable to differentiate males and females with an accuracy rate of 88.7%. In our study, this rate was 98.1%. They suggest that sex can be correctly predicted with a rate of 81.7% based on femoral neck width. In our study this rate was 93.5%. Slaus et al. (2003), in his study on a Croatian population, constructed a discriminant function for sex estimation from femur. In contrast to our study, he suggested that among the measurements taken from femur, the circumference of femoral head gave the best results, followed by the epicondylar width. Another study in Thailand, using a new collection of skeletons from the University of Chiang Mai's Department of Anatomy, attempted to establish a standard for determining the sex of the femur. The sample consisted of 104 people (70 males, 34 females). Six standard osteometric dimensions, consisting of maximum length (C-C), maximum head diameter (A-A), head diameter (E-E) and epicondylar width (EAM), were measured and analyzed with step-by-step discriminant function statistics. The regions with the best results for the sex prediction resulted in a combination of Proximale (A-A) and Distal (EAM) points, with a 94.2% accuracy ratio (King et al., 1998). In our study, we can say that the distinctive powers of (A-A) 93.5% and (EAM) 98.1% respectively are excellent.

Kanz et al. (2015) studied the femurs of 127 Austrian individuals, 72 females and 55 males, and suggested that sex estimation based on maximum head diameter and head circumference in univariate analysis can be correctly estimated 87.8% and 84.8%, respectively. Chatterjee et al. (2020) conducted a study in the Indian population was reported to be the best predictor of sex with an accuracy rate of 80.6%. In this study, the sex from the diameter of the femoral head can be correctly predicted with an accuracy rate of 91.6%. Clavero et al. (2015) reported an accuracy rate of 98.3% with the logistic regression method he developed in his study based on measurements from computed tomography images, as in this study. In our study, the rate we found with the logistic regression method is 91%.

Curate et al. (2017) applied various machine learning approaches and developed logistic regression analysis. They took linear measurements at 15 different points from a training sample (100 females, 100 males) from the Coimbra Identified Skeleton Collection (Curate et al., 2017). These are similar to our vertical and transverse plane measurements. Curate correctly classified sex 84.0 to 92.5%. In another study, Curate et al. (2016) used logistic regression analysis with measurements taken from 114 females and 138 males on two measurements, femoral neck width and femoral neck length from the proximal part. They correctly predicted sex in 82.5-85.7% of individuals. In our study, confusion Matrix (LOOCV) was used and 91% correct classification success was achieved.

In a study by Knecht et al. (2023) using machine learning methods to predict sex from long bones, five machine learning methods were used to predict sex: linear discriminant analysis (LDA), penalized logistic regression (PLR), random forest (RF), support vector machine (SVM) and artificial neural network (ANN). The different classification algorithms using whole bones produced highly accurate models with cross-validation ranging from 90% to 92% in the validation sample. Classification with isolated bones ranged from 83.3% to 90.3% in the validation sample. In our study, cross-validation was performed, the model was built and the success rate for sex assignment was 91% according to logistic regression analysis.

Conclusions

Based on the fact that the femur cannot always be obtained as a whole, especially in forensic cases where mass deaths occur and in anthropological studies, the effect of anthropometric measurements taken from the distal and proximal end of the femur on sex estimation was evaluated in this study. Linear measurements from both the proximal and distal ends of the femur can be used to make very reliable sex estimates. However, angular measurements such as the angle of inclination and intercodylar angle were not significantly different between the two sexes and therefore these two parameters are not suitable variables for sex prediction. The findings obtained in this study show that E-E, C-C, A-A, B-B measurements taken from the proximal end of the femur are reliable parameters with an accuracy rate of 97.0%, 94.6%, 93.5%, 91.6% respectively, whereas epicondylar width taken from the distal end is the most reliable parameter with an accuracy rate of 98.1%. Our study has revealed important results and will contribute to future studies in forensic anthropology and forensic medicine in cases requiring sex determination from the distal or proximal end of the femur, especially in cases where bone remains are scattered, fragmented and lost. In addition to these measurements, there are other measurements and methods that can be used for sex determination in different populations and more studies are needed.

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