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Research Paper: Collo-Diaphyseal Angle as an Optimal Anthropometric Criterion of Femur in Gender Determination

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ABSTRACT

Background: Gender determination is an important challenge in the identification of skeletal remnants and dismembered bodies. The femur bone is more likely to be preserved during accidents and over time; thus, it is one of the most useful bones in gender determination.

Methods: This cross-sectional study was conducted on 54 fresh femur pairs of >19-year-old Iranians without anomalies or trauma. We studied the length of the femur, vertical head diameter, bicondylar width, shaft angle with the horizon, and collo-diaphyseal angle in male and female samples. Data were analyzed in SPSS using t-test and Receiver Operating Characteristic curves. $P<0.05$ was considered as statistically significant.

Results: The samples' mean age was 37 years in males and 41 years in females. The mean values of measurements were not significantly different between the left and right femurs ($P>0.05$). The vertical head diameter, maximum length, bicondylar width, and the shaft angle were significantly larger in the males, compared to females. The mean degree of collo-diaphyseal angle was significantly wider in females, compared to males ($P<0.05$). The highest precision of gender differentiation belonged to the collo-diaphyseal angle (96.3%) and the lowest one belonged to the vertical head diameter (77.8%).

Conclusion: Based on our findings, even with the existence of only one femur bone, gender determination can be achieved with high precision. Collo-diaphyseal angle would be helpful in gender determination, even with the sole availability of the proximal part of the femur.

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1. Introduction

Identification based on human body parts, including the skeleton or mutilated bodies, is an important, yet difficult task in forensic medicine. The first step to identify a corpse is gender determination [1-4].

When the whole skeleton is available, gender determination is easier to perform; however, it is difficult in the lack of that [5]. The dimensions of long bones are larger in males, compared to females [6]. Such characteristics are influenced by factors such as environment, race, and nutrition [7]. Gender determination should not be based on one measurement, because multiple measurements from different bones provide more accurate results [6]. These characteristics change in different races over time (from birth to death) and due to different diseases. Skeletal growth and development are influenced by multiple factors leading to alternations in bone parameters and skeletal ratios in different geographical locations [8].

Chandrakanth et al. reported gender determination by the hip bone and skull were 90%-95% and 80% accurate, respectively [1]. The femur is an important bone in anthropometric studies, including gender and age determination [9]. Alunni et al. and Kanz et al. addressed the characteristics of the femoral head with a 95% precision in gender determination for Transversal Head Diameter (THD) and Head Circumference (HC), and 94.8% for Vertical Head Diameter (VHD) [10, 11]. Bernard Knight recognized the size of the femoral head as a good criterion for gender determination [6].

There are racial anthropometric differences in bones, and gender affects these characteristics. Thus, the present research aimed to compare the precision of anthropometric characteristics of the femur in gender determination and evaluate the cut-off points of these criteria.

2. Material and Methods

This cross-sectional study was conducted on the femurs provided from the Dissection Hall of the Legal Medicine Organization in Tehran City, Iran to the Tissue Bank and Research Center of Tehran University of Medical Sciences from 2015 to 2017. Fifty-four right and left femur pairs of the same individuals were obtained for analysis. The ossification of bones is almost always complete at the age of 19 [12]. This study was approved by the Institutional Review Board of Tehran University of Medical Sciences (code: 93.04.30.27203).

Initially, soft tissues were removed from the bones using a scalpel. Due to the importance of sterility for grafting purposes, all measurements were performed with sterile instruments under sterile conditions. Measurements were independently performed by two experienced forensic medicine specialists blinded to the gender of samples.

In this study, the following measurements were obtained and analyzed: 1. The maximum length of the femur (length from head to medial condyle); 2. Bicondylar width (maximum width between the 2 condyles, parallel to the infracondylar plane); 3. The maximum vertical diameter of the femoral head in its joint surface; 4. Collo-diaphyseal angle (angle between the femoral neck and femoral shaft); 5. Femoral shaft angle with the horizontal (angle between the femur and the horizontal when both condyles are placed on a horizontal line) (Table 1).

We used a metallic ruler for measuring femoral length; a caliper for measuring bicondylar width and vertical head diameter; and a goniometer for measuring the

Table 1. Definition of the indicators, methodology and measurement tools

Index	Definition	Measurement Tool	Unit
The maximum length of the femur	The maximum length from the head to the medial condyle [10]	Metallic ruler	Centimeter
Vertical head diameter	The maximum vertical diameter of the femoral head [10]	Caliper	Centimeter
Bicondylar width	The maximum width between the two condylar, parallel to the intercondylar plane [11]	Caliper	Centimeter
Collo-diaphyseal angle	The angle between the femoral neck and the femoral shaft [12]	Goniometer	Degree for angles
Femoral shaft angle with the horizon	The angle between the femur and horizon when both condyles are placed in a horizontal line [12]	Goniometer	Degree for angles

collo-diaphyseal angle and femoral shaft angle with the horizontal. The measurement units included centimeter for femoral dimensions and degree for angles.

The informed consents were obtained from the first degree relatives of cadavers. The samples belonged to cadavers aged ≥20 who underwent forensic autopsy in the Legal Medicine Organization. Then, the femur bones were sent to the Tissue Bank and Research Center of Tehran University of Medical Sciences in Imam Khomeini Hospital for bone graft purposes. A separate consent was also acquired. The inclusion criteria consisted of ≥20 years of age and available valid identification documents. The exclusion criteria were a fractured bone and the skeletal anomalies of the femur.

The obtained data were analyzed in SPSS using t-test and Receiver Operating Characteristic (ROC) curves. Moreover, P<0.05 was considered as statistically significant [13]. Intra-observer reliability was separately assessed by both observers in 20 random samples. To explore the inter-observer reliability, the observers were blinded to the sample details. Only 4% and 9% of the measurements differed in intra- and inter-observer examinations, respectively. Intra- and inter-observer reliabilities (weighted kappa) for gender determination were 0.94 and 0.92, respectively.

3. Results

The mean age of the study samples was 39 years, the mean age of males and females were 37 and 41 years, respectively, with no statistically significant difference (P=0.32) (Table 2). Based on the Kolmogorov–Smirnov test [14], age had a normal distribution in the studied samples. No statistically significant difference was observed in the mean anthropometric measurement scores of the studied right and left femurs (P>0.05) (Table 3).

The mean score of vertical head diameter was 4.64cm in males and 4.16cm in females, the same value for maximum length was 45.10cm in males and 41.31 in females. Moreover, bicondylar width mean score was 8.37cm in males and 7.33 in females; and the mean

Table 2. The mean age of studied males and females

Gender	Number*	Mean±SD	Min.	Max.
Male	54	36.85±13.24	20	58
Female	54	41.19±13.58	20	66
Total	108	39.02±13.46	20	66

*The femur pairs (right and left sides).

Table 3. The mean values of anthropometric measurements of the studied right and left femurs

Variable	Side	Mean±SD	Min.	Max.	P
Vertical diameter of the femoral head	R*	4.41±0.32	3.85	5.15	>0.05
	L**	4.39±0.33	3.75	5.20	
The maximum length of the femur	R	43.20±2.89	38	49	>0.05
	L	43.20±2.89	38	49	
Bicondylar width	R	7.85±0.76	6.4	9.3	>0.05
	L	7.80±0.72	6.7	9.4	
Femoral shaft angle with the horizon	R	79.29±4.51	70	89	>0.05
	L	79.64±4.88	70	88	
Collodiaphyseal angle	R	47.48±8.92	35	62	>0.05
	L	47.79±8.72	35	63	

*Right; **Left

Table 4. The mean values anthropometric measurements of and the studied right and left femurs in both genders

Side	Variable	Gender	Mean±SD	Min.	Max.	P
Right	The vertical diameter of the femoral head	Male	4.64±0.22	4.20	5.15	<0.0001
		Female	4.18±0.23	4.20	5.20	
	The maximum length of the femur	Male	45.10±2.67	40	49	<0.0001
		Female	41.31±1.56	38	45	
	Bicondylar width	Male	8.37±0.61	6.6	9.3	<0.0001
		Female	7.33±0.5	6.7	8.5	
	Femoral shaft angle with horizon	Male	81.96±2.73	78	89	<0.0001
		Female	76.63±4.39	70	85	
	Collo-diaphyseal angle	Male	39.77±3.72	35	47	<0.0001
		Female	55.18±5.01	38	62	
Left	The vertical diameter of the femoral head	Male	4.64±0.23	3.85	4.60	<0.0001
		Female	4.15±0.21	3.75	4.60	
	The maximum length of the femur	Male	45.10±2.67	40	49	<0.0001
		Female	41.29±1.56	38	45	
	Bicondylar width	Male	8.28±0.58	6.7	9.4	<0.0001
		Female	7.31±0.48	6.8	8.4	
	Femoral shaft angle with horizon	Male	82.77±2.75	77	88	<0.0001
		Female	76.51±4.55	70	87	
	Collo-diaphyseal angle	Male	40.51±3.69	35	49	<0.0001
		Female	55.07±5.60	38	63	

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degree of femoral shaft angle with the horizontal was 81.96 degree in males and 76.63 in females. The mean score of 4 measurements were significantly larger in males; however, the mean degree of collo-diaphyseal angle was significantly wider in females (55.18), compared to males (39.77) (P<0.05) (Table 4).

According to the statistically significant differences observed between the genders, ROC curves were drawn to assess the precision of each variable in gender determination. The Area Under the Curve (AUC) for ROC curves are presented in Table 5 and Figure 1. The AUC of all femoral criteria was higher than 0.83. Using ROC curves, we identified distinction points for each measured characteristic.

Table 6 indicates the sensitivity, specificity, positive and negative predictive values, and the precision rates of anthropometric characteristics of studied femurs. Regarding the right femur, and using the distinction point for each variable, the highest precision for gender determination belonged to the collo-diaphyseal angle (96.3%), followed by bicondylar width (87%), maximum length (81.5%), the angle of femoral shaft with the horizontal (79.6%), and vertical head diameter (77.8%).

In respect of the left femur, collo-diaphyseal angle had the highest precision (94.4%) in gender determination, followed by vertical head diameter, bicondylar width, femoral shaft angle with the horizontal (83.3%), and maximum length (81.5%) (Table 6). The results of Wilk's Lambda test are presented in Table 7. Based

Table 5. AUC for ROC curves of the studied femoral anthropometric measurements

Variable	Side	Area	SE	Asymptotic Sig.	Asymptotic 95% CI	
					Lower	Upper
The vertical diameter of the femoral head	R	0.834	0.060	0.000	0.716	0.952
	L	0.834	0.060	0.000	0.716	0.952
The maximum length of femur	R	0.880	0.048	0.000	0.786	0.974
	L	0.880	0.048	0.000	0.786	0.974
Bicondylar width	R	0.890	0.047	0.000	0.797	0.983
	L	0.885	0.049	0.000	0.790	0.981
Femoral shaft angle with horizon	R	0.975	0.025	0.000	0.927	1.024
	L	0.968	0.028	0.000	0.914	1.023
Collo-diaphyseal angle	R	0.841	0.059	0.000	0.726	0.956
	L	0.866	0.055	0.000	0.759	0.973

* Right, ** Left.

on this test, all variables were statistically significant (P<0.05). Using logistic regression analysis for femoral shaft angle with the horizontal and maximum femoral length, the following formulas were generated for gender determination:

X=15.044+(the maximum length of right femur x 0.845)-(the angle between shaft and neck of right femur x 0.449)

X=19.648+(the maximum length of left femur x 0.995)-(the angle between shaft and neck of left femur x 0.494)

Table 6. The mean, sensitivity, specificity, positive and negative predictive values, and precision of anthropometric measurements

Variable	Side	Distinction Point	Sensitivity	Specificity	Positive Predictive Value	Negative Predictive Value	Accuracy (%)
The vertical diameter of the femoral head	R	4.32	88.9	66.7	72.7	85.7	77.8
	L	4.32	90.9	78.1	74.1	92.6	83.3
The maximum length of the femur	R	42.35	85.2	77.8	79.3	84	81.5
	L	42.35	85.2	77.8	79.3	84	81.5
Bicondylar width	R	7.95	88.9	85.2	85.7	88.5	87%
	L	7.95	88.9	77.8	80	87.5	83.3
Femoral shaft angle with the horizon	R	79.5	85.2	74.1	76.7	83.3	79.6
	L	79.5	92.6	74.1	78.1	90.9	83.3
Collo-diaphyseal angle	R	46	96.3	96.3	96.3	96.3	96.3
	L	47.5	96.3	92.6	92.9	92.2	94.4

Table 7. Wilk's Lambda test results

Multivariate test				
Effect		F	Sig.	Partial Eta Squared
Gender	Wilks' Lambda test	99.8	0.000	0.83
	Source	F	Sig.	Partial Eta Squared
	The maximum length of femur	82.9	0.000	0.439
	The vertical diameter of the femoral head	40.4	0.000	0.276
Gender	Bicondylar width	91.5	0.000	0.463
	Femoral shaft angle with horizon	66.7	0.000	0.386
	Collo-diaphyseal angle	292.7	0.000	0.734

In these formulas, X<0 and X<1 characterized male and female, respectively.

4. Discussion

There are two main methods of gender estimation (morphological and metric) [2]. The femoral measurements are important in gender determination [15-18]. The femoral length, head diameter, bicondylar width, femoral shaft angle with the horizontal, and collo-diaphyseal angle are used for this purpose [17-21]. The femoral head diameter is a highly significant variable in gender determination [17, 18, 20].

In the present study, the obtained mean femoral length was similar to the findings of Kanz et al. on Australian femurs who died before 1949 [11]. It was also consistent with Harma et al. findings who studied the radiographs of 18- to 68-year old white Anatolians, and Lee et al. who studied the femoral Computed Tomography (CT) scans of 21- to 62-year old Koreans [17, 18]. Mall et al. investigated 16- to 92-year old German corpses; Y Yoshioka et al. explored Canadian femurs and reported larger femoral lengths for males and females, compared to our findings [19, 22]. This can stem from a wider age range, as well as racial and nutritional differences between the studied samples.

In this study, the mean vertical head diameter in both genders was almost similar to the findings of Kanz et al. and Alunni et al. who studied the femur in 70- to 95-year-old French corpses [21, 10]. Mall et al. Harma et al. Lee J et al. and Y Yoshioka et al. reported larger vertical femoral head diameter for males and females, compared to our findings [17-19, 22].

Our obtained bicondylar width mean scores were similar to those of Mall et al. Lee et al. , Kanz et al. and Alunni-Perret et al. who studied French corpses born in 1910 who died from 1998 to 2006 [18, 19, 11, 23]. The study by Hussain et al. on CT images of 20- to 38-year-old Malaysians reported a smaller mean score to our findings [24]. Y Yoshioka et al. reported a larger bicondylar width for males and females, compared to our finding [22]. This can be due to a difference in the methodology and measurement tools, as well as racial and nutritional differences [7, 24].

Regarding the collo-diaphyseal angle, our results were in line with Tahir et al. study on Nigerian bodies [25]. The mean degree of collo-diaphyseal angle in our studied females was consistent with those of Akhlaghi et al. on the femoral radiographs of 24- to 57-year-old Iranian adults [15]. It was also similar to Bhattacharya et al. research from Calcutta, India on the femoral radiographs of Indians with an average age of 59 years; however, the angle in their studied males was greater than our obtained data [26]. Y Yoshioka et al. reported a larger mean degree of collo-diaphyseal angle for males than females, compared to our findings; However, these results were not statistically significant (P>0.05) [22]. This can be due to a difference in racial, methodological and nutritional differences [7, 24].

The average angle of the femoral shaft with the horizontal horizon in our study was similar to documented numbers in Knight's Forensic Pathology; however, there was no significant difference in the results of Y Yoshioka et al. between males (85) and females (85) (P>0.05) [22, 6]. Inconsistent with the previous studies, including Bhattacharya et al. , Alunni et al. and Alunni-Perret et al.

Table 8. Comparing the precision of different femoral measurements in gender determination between our study and previous reports

Study	Method	Population	Value	Results			
				Male	Female	P	Accuracy (%)
Mall et al. [19]	Direct	Germany	The maximum length of femur*	46.4	43.4	<0.05	67.7
			Vertical Head Diameter*	4.9	4.4	<0.05	86.8
			Bicondylar width	8.4	7.7	<0.05	72.4
Lee JH et al. [18]	CT	Korea	The maximum length of femur*	44.2	40.6	<0.05	77
			Vertical Head Diameter*	4.8	4.3	<0.05	83
			Bicondylar width*	8.3	7.4	<0.05	85.9
Kanz et al. [11]	Direct	Australia	The maximum length of femur*	44.9	41.3	<0.05	86.5
			Vertical Head Diameter*	4.7	4.2	<0.05	87.8
			Bicondylar width*	8.0	7.2	<0.05	80.6
Harma et al. [17]	CT	Eastern Anatolia	The maximum length of femur*	44.8	41.9	<0.05	83.3
			Vertical Head Diameter*	4.9	4.3	<0.05	77
Soni et al. [21]	Direct	North Western India	The maximum length of femur*	43.9	41.0	<0.05	
			Vertical Head Diameter*	4.4	4.0	<0.05	88.4
			Bicondylar width*	7.6	6.9	<0.05	86
Md. Laeeque et al.	Direct	Maharashtra, India	Vertical Head Diameter*	4.3	3.7	<0.05	50
			Bicondylar width*	7.6	6.5	<0.05	46
Yoshioka et al. [22]	Direct	Canada	The maximum length of femur*	46.6	44.2	<0.05	
			Vertical Head Diameter*	5.2	4.5	<0.05	
			Bicondylar width*	9.0	8.0	<0.05	
			Femoral shaft angle with horizon**	85	85	>0.05	
			Collo-diaphyseal angle**	51	47	>0.05	
Akhlaghi et al. [15]	Radioghraphy	Iran	Collo-diaphyseal angle**	53	55	<0.05	59
The present Study	Direct	Iran	The maximum length of femur*	45.1	41.3	<0.05	81.5
			Vertical Head Diameter*	4.6	4.2	<0.05	77.8
			Bicondylar width*	8.4	7.3	<0.05	87
			Femoral shaft angle with horizon**	82	77	<0.05	79.6
			Collo-diaphyseal angle**	38	55	<0.05	96.3

* Centimeter; ** Degree; P<0.05 is considered as statistically significant.

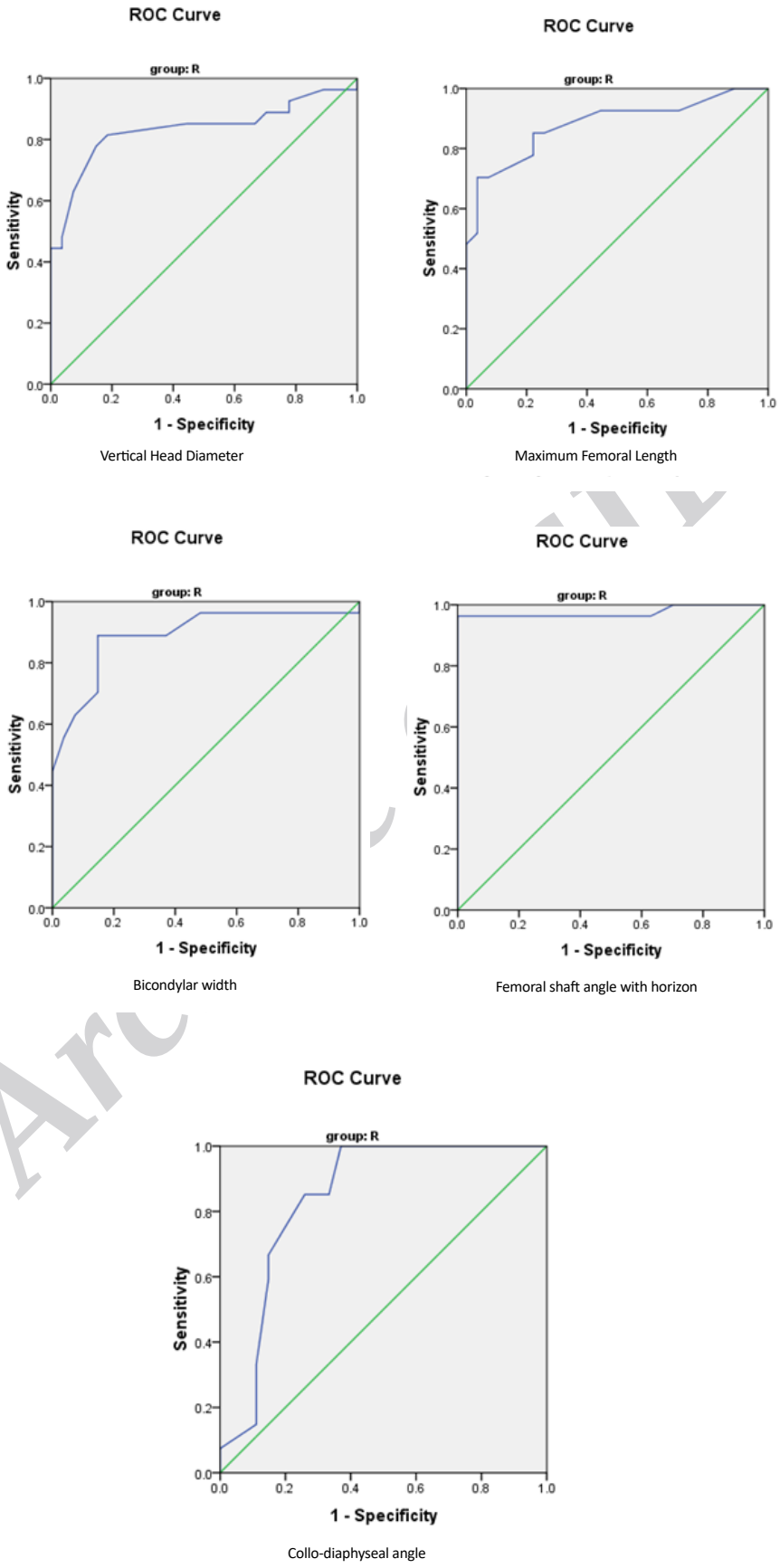

Figure 1. The ROC curve of all femur indices

we observed no significant difference between the right and left femoral measurements [10, 23, 26].

In our study, vertical head diameter, maximum length, bicondylar width and the femoral shaft angle with the horizontal were significantly higher in males, compared to females. This data is in accordance with Lee et al. Mall et al. Harma et al. Y Yoshioka et al. findings, and documented numbers in Knight's Forensic Pathology; however, in line with studies by Godycki, Tahir et al. and Akhlaghi et al. our obtained collo-diaphyseal angle was significantly wider in females, compared to males [15, 17-19, 22, 25, 6, 27]. Bhattacharya et al. and Y Yoshioka et al. have not reported a significant difference between the two genders in collo-diaphyseal angle [22, 27].

The precision of gender determination for maximum femoral length was 86.5% in Kanz et al. 77% in Lee et al. and 67.7% in Mall et al. investigations, and 81.5% in our study [18, 19, 11]. The precision for vertical head diameter in gender determination was 94.8% in Alunni et al. 86.8% in Mall et al. and 83% in Lee et al. studies, and 77.8% in our study [18, 19, 10]. Bicondylar width for gender determination had a precision of 95.4% in Alunni-Perret et al. 85.9% in Lee et al. 81.4% in Mall et al. and 80.6% in Kanz et al. studies, and 87% in ours [18, 19, 11, 23]. The precision of collo-diaphyseal angle in the study by Akhlaghi et al. was 59%, while it was 96.3% in the present research [15]. This number was 79.6% for the angle of the femoral shaft with the horizontal. The variability of precision in different studies can be due to differences in genetics, race, nutrition, environment, methodology, studied age groups and measurement techniques [6, 7, 10].

In this study, the collo-diaphyseal angle and vertical head diameter had the highest and lowest precision for gender determination, respectively. Kanz et al. reported the highest precision for the femoral length (86.5%) [11]. Mall et al. and Lee et al. reported the highest precision for the vertical diameter of the femoral head (86.8%) and bicondylar width (85.9%), respectively [19, 18]. Table 8 summarizes the comparison of precision rates in gender determination for different femoral measurements between our study and previous reports.

5. Conclusion

The accuracy of different anthropometric criteria for femur is not the same and sometimes only a part of the bone is available to identify and predict the gender. Thus, this study compared the accuracy of femoral criteria. The precision of collo-diaphyseal angle in gender determination is high (95.5%). Furthermore, even with the proximal femur available, gender determination can be achieved with high precision in our population. The anthropometric criteria of bones, including the femur, are influenced by several factors such as race, geographical location, activity, and nutrition. Therefore, further studies are required to explore gender differences in different populations. It is recommended that future studies be conducted with an appropriate sample size and, if possible, on fresh bones.

Ethical Considerations

Compliance with ethical guidelines

Informed consent for the research was obtained from the first degree relatives of the cadavers. This study was approved in the Ethics Committee of Tehran University of Medical Sciences (Code: 93.04.30.27204).

Funding

This study was approved by the Institutional Review Board of Tehran University of Medical Sciences.

Authors' contributions

All authors contributed in designing, running, and writing all parts of the research.

Conflict of interest

The authors declared no conflict of interest.

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