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ORIGINAL ARTICLE

Age and Sex Discrimination via Tibial Measurement Estimation by Computed Tomography in Aswan governorate

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ABSTRACT

Keyword: Tibia, Measurement, Age, Sex, Discrimination CT scan.

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Background: There are numerous applications for computerized tomography in anthropometric studies and the analysis of skeletal remains. By examining computerized models of the tibia bone, it was found to be significant indicators of sex and age and this was significant advance in forensic science. **Aim:** This study aimed to test the accuracy of age and sex identification on the basis of computed tomographic image from different tibial measurement. **Methodology:** This observational cross-sectional study was conducted in the period from September 2019 to June 2023 on 200 living Egyptian persons at Aswan governorate submitted to spiral computed tomography of the Tibia. **Results:** there was significant (<0.001) difference between male and female, age group ≤50 years and age group >50 years and between stature <165 cm and ≥165 cm according to different diameters (AB, CD and EF). Also, A-B distance was the most accurate (81.5%), C-D distance was the most sensitive (83%), and A-B distance was the most specific (93%). **Conclusion:** this study highlights that the morphological differences represented by tibial dimensions between males and females, and in respect to their corresponding age groups were highly significantly different. This study provided an equation to predict a person's height based on the length of the tibia. Therefore, the current investigation yielded outstanding findings that are applicable in a forensic anthropological setting.

INTRODUCTION

One of the main goals of forensic medical investigations is to identify unrecognized human remains. Basic information on the individual's age, gender, height, and other anthropological traits has to be gathered in order to approximate a biological profile that will allow us to confirm identity. Forensic pathologists frequently examine highly decomposed, burned, or otherwise damaged human remains **(1)**. Particularly in cases that result in significant mortality, forensic investigators work to determine the four main components of biological identification (sex, age, ethnic origin, and stature) **(2)**.

An essential component of forensic analysis is determining an individual's age. Among the many biomarkers that can be used to identify missing persons whose remains have been located is age at death **(3)**. The most suitable techniques are determined by the age distribution and the existence or lack of skeletal features. Bethard and VanSickle (2020) state that different methods must be used when determining the age of death in a fetus, baby, child, or other immature individual than when examining an adult's skeleton **(4)**.

Making a precise sex prediction from measurements of bone fragments is the most important step in the identification process **(5)**. Skeletal remains are sensitive for sex estimation, but they cannot be used when human and skeletal remains are only partially found. In these situations, attempts are made to estimate sex or height using other body parts **(6)**. The accuracy of sex identification depends on the degree of sexual dimorphism the skeleton exhibits, but damaged or incomplete human skeletal remains are commonly used in forensic investigations **(7)**.

The ability to determine sex from these materials becomes essential when mass murderers attempt to disfigure their victims to prevent identification or when bones are mixed, burned, and broken following a natural disaster **(8, 9)**. The errors presented here are in line with earlier studies that estimated sex using measurements from the lower limbs, particularly the tibia, and frequently obtained accuracies of over 80% **(9-11)**.

Because it showed the strongest correlation with stature in earlier research on comparable populations, the tibia was chosen as the ideal skeletal component **(4, 6-9),** as well as showing a significant degree of sexual dimorphism **(12).**

There are numerous applications for computerized tomography in anthropometric studies and the analysis of skeletal remains **(13)**. Examining sexual dimorphism helps one comprehend the overall intersexual divergence of the same species and provides information about how selective forces affect each sex **(14)**. Compared to differences in standard cortical metrics of radius and tibia, age-related differences in cortical porosity as measured by HR-pQCT are more noticeable. These structural variations have greater biomechanical significance for men and women as they age, and they offer discriminating information about the effects of menopause on bone quality **(15)**.

The goal of this study was to test the accuracy of age and sex identification on the basis of computed tomographic image from different tibial measurement among a known population in Aswan.

PATIENTS AND METHODS

This observational cross-sectional study was conducted in Aswan university hospital in the period from September 2019 to June 2023. The study involved 200 living Egyptian persons (100 males & 100 females), each group was subdivided to include 50 right and 50 left tibia) in Aswan governorate submitted to spiral computed tomography of the Tibia.

Inclusion criteria were Egyptian residents in Aswan governorate without history of previous knee, ankle or tibial fracture and aged > 30 years old. On the other hand, those with fractured tibia, previous history of knee or ankle surgery, history of underlying endocrine, metabolic or nutritional disorder were excluded.

Procedure

Every individual is subjected to measurement of his/her stature in centimeters; the length, proximal and distal breadth of tibia right & left are measured by CT **(Fig. 1)**:

- Landmark A-B [A] i.e., point (A): on outer most point on lateral condyle and point (B): on outer most point on medial condyle.
- Landmark C-D [B] i.e., point (C): on outer most point on medial malleolus and point (D): on outer most point on lateral end.
- Landmark E-F [C] i.e., point (E): on upper most point and point (F): on lower most point.

Fig. 1: Normal Tibial Measurement by CT

Statistical analysis

Data analysis was undertaken using IBM-SPSS version 26 **(16)**. Categorical data were presented as frequencies and percentages. Numerical data were checked for normality by Shapiro- walk test and presented as mean and standard deviation (SD) or median and range according to their distribution. Independent Sample T-test/Mann Whitney U test was used to compare mean/median difference between the two groups as appropriate.

Linear/Logistic regression analysis was calculated to investigate the independent predictor power of measurements (Odds Ratio -OR-, 95% confidence interval -95% CI- and p-value-). ROC curve was depicted to explore the diagnostic performance/cutoff of different parameters in predicting age and sex, analyzed as area under the curve (AUC), standard error (SE) and 95% CI. Validity statistics (sensitivity, specificity, positive and negative predictive value –PPV & NPV-) were calculated. The level of significance was considered at p-value < 0.05.

Ethical considerations

Institutional Ethics and Research Review Board (IRB no. 69/6/16) of the Faculty of Medicine at Aswan University approved the study's methodology. Anonymity and confidentiality were assured. Before participation, the purpose and nature of the study as well as risks and benefits were fully explained. An informed written consent was a taken from the cases. This work was in line with the guidelines of Helsinki Declaration **(17)** and the STROBE guidelines for observational studies **(18)**.

RESULTS

In this study, 200 Egyptian persons (lived in Aswan) were included to test the accuracy of CT-based age and sex identification from different tibial measurement.
Table 1 described the baseline data of the study population. Age ranged from 31 to 70 years with a mean of 49.6 ± 10.1 years. For sex, male/female ratio was 1:1. Regarding stature, it ranged from 155 to 183 cm with a mean of 164.8 ± 6.9 cm and accordingly; about two-thirds (n=121) had stature <165 cm and 39.5% (n=79) had stature ≥165 cm.

Table 1: Basic Characteristics of the Studied Population

	n = 200	**%**
Sex		
• Male	100	50.0
• Female	100	50.0
Age (years)		
• Min. - Max.	31 – 70	
• Mean ± SD	49.56 ± 10.1	
stature (cm)		
• <165 cm	121	60.5
• ≥165 cm	79	39.5
• Min. - Max.	155 – 183	
• Mean ± SD	164.81 ± 6.9	

As shown in **fig.2**, One-quarter of the studied groups were 30-40 years (23 male/27 female); 26.5% were 41-50 years (24 male/29 female); about one-third were 51-60 years (36 male/31 female); and 15% were over 60 years old (17 male/13 female). This association was insignificant (p=0.637).

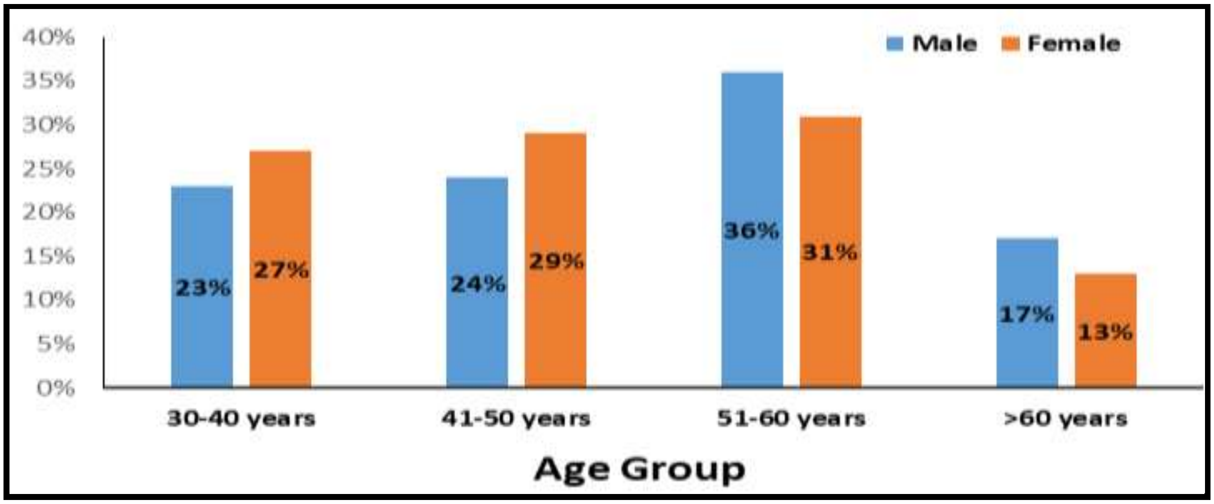

Fig. 2: Age Distribution according to Patient's Sex

Table 2 illustrated the association between sex and tibial measurements, there were statistically significant (p < 0.001) difference between males and females i.e., males had longer measurements (A-B: 7.3 ± 0.7, C-D: 4.8 ± 0.3 and E-F: 37.1 ± 1.8 cm) vs. females (A-B: 6.6 ± 0.2, C-D: 4.4 ± 0.2 and E-F: 35.1 ± 1.9 cm).

Table 2: Relationship between Tibial Measurements and Sex

Measurements (cm)	Total (n=200)	Male (n=100)	Female (n=100)	t-Stat.	P-value
Lateral & medial condyle (A-B)					
• **Min. - Max.**	5.6 - 8.3	5.6 - 8.3	6.2 - 7.7		
• **Mean ± SD**	6.95 ± 0.6	7.29 ± 0.7	6.61 ± 0.2	9.29	**<0.001***
Medial malleolus & lateral end of the tibia (C-D)					
• **Min.-Max.**	4.2 - 5.5	4.2 - 5.5	4.2 - 4.8		
• **Mean ± SD**	4.60 ± 0.3	4.78 ± 0.3	4.41 ± 0.2	10.21	**<0.001***
Length of the tibia (E-F)					
• **Min.-Max.**	31 - 40.1	31.5 - 40.1	31 - 37.9		
• **Mean ± SD**	36.07 ± 2.2	37.14 ± 1.8	35.01 ± 1.9	8.01	**<0.001***

***Independent Sample T test compare mean between two groups**

Table 3 presented the relationship between patient's age and tibial measurements, there were statistically significant (p < 0.001) difference according to age i.e., younger age group [30 - 50 years] had longer measurements (A-B: 7.1 ± 0.6, C-D: 4.7 ± 0.3 and E-F: 37.1 ± 1.8 cm) vs. older age group [50 - 70 years] (A-B: 6.8 ± 0.6, C-D: 4.5 ± 0.3 and E-F: 35.07 ± 2.1 cm).

Table 3: Relationship between Tibial Measurements and Age

Measurements (cm)	Age groups 30-50 years (n = 103)	 50-70 years (n = 97)	t-Stat.	P-value
Lateral & medial condyle (A-B)				
• **Min.-Max.**	6.3 - 8.2	5.6 - 8.3		
• **Mean ± SD**	7.11 ± 0.6	6.78 ± 0.6	3.972	**<0.001****
Medial malleolus & lateral end of the tibia (C-D)				
• **Min.-Max.**	4.2 - 5.4	4.2 - 5.5		
• **Mean ± SD**	4.69 ± 0.3	4.5 ± 0.3	4.404	**<0.001****
Length of the tibia (E-F)				
• **Min.-Max.**	31.4 - 40.1	31 - 40		
• **Mean ± SD**	37.01 ± 1.8	35.07 ± 2.1	7.047	**<0.001****

***Independent Sample T test compare mean between two groups**

The interaction between age and sex for the tibial measurements was presented in **table 4**. For age group 30-50 years, there were statistically significant (p < 0.001) difference between males and females i.e., males had longer measurements (A-B: 7.7 ± 0.4, C-D: 4.9 ± 0.3 and E-F: 38.3 ± 1.3 cm) vs. females (A-B: 6.7 ± 0.3, C-D: 4.5 ± 0.2 and E-F: 35.9 ± 1.4 cm) **(Fig. 3)**.

Table 4: Relationship between Tibial Measurements and Sex stratified by Age

Measurements (cm)	Age group [30-50 years] (n=103) Male (n=47)	 Female (n=56)	t	P-value
Lateral & medial condyle (A-B)				
• Min.-Max.	6.4 - 8.2	6.3 - 7.7		
• Mean ± SD	7.65 ± 0.4	6.66 ± 0.3	14.458	**<0.001****

Medial malleolus & lateral end of the tibia (C-D)				
• Min.-Max.	4.4 - 5.4	4.2 - 4.8		
• Mean ± SD	4.97 ± 0.3	4.45 ± 0.2	12.741	**<0.001****
Length of the tibia (E-F)				
• Min.-Max.	34.8 - 40.1	31.4 - 37.9		
• Mean ± SD	38.33 ± 1.3	35.91 ± 1.4	9.157	**<0.001****
Measurements (cm)	**Age group [50-70 years] (n=97)**		**t**	**P. value**
	Male (n=53)	**Female (n=44)**		
Lateral & medial condyle (A-B)				
• Min.-Max.	5.6 - 8.3	6.2 - 7.4		
• Mean ± SD	6.97 ± 0.7	6.55 ± 0.2	3.766	**<0.001****
Medial malleolus & lateral end of the tibia (C-D)				
• Min.-Max.	4.2 - 5.5	4.2 - 4.8		
• Mean ± SD	4.62 ± 0.3	4.35 ± 0.2	5.277	**<0.001****
Length of the tibia (E-F)				
• Min.-Max.	31.5 - 40	31 - 37.9		
• Mean ± SD	36.08 ± 1.5	33.85 ± 2.1	6.060	**<0.001****

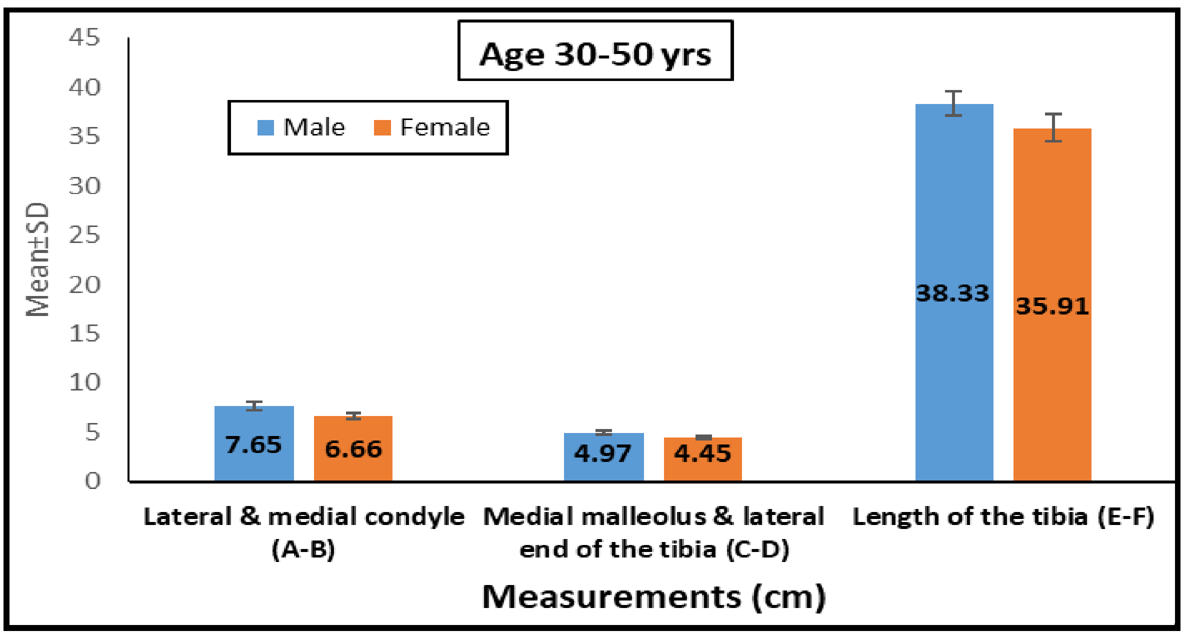

Fig. 3: Sex Distribution of Tibial Measurements Age Group [30-50 year]

For age group 50-70 years, there were statistically significant ($p < 0.001$) difference between males and females i.e., males had longer measurements (A-B: 6.9 ± 0.7, C-D: 4.6 ± 0.3 and E-F: 36.1 ± 1.5 cm) vs. females (A-B: 6.6 ± 0.2, C-D: 4.4 ± 0.2 and E-F: 33.9 ± 2.1 cm) **(Fig. 4)**.

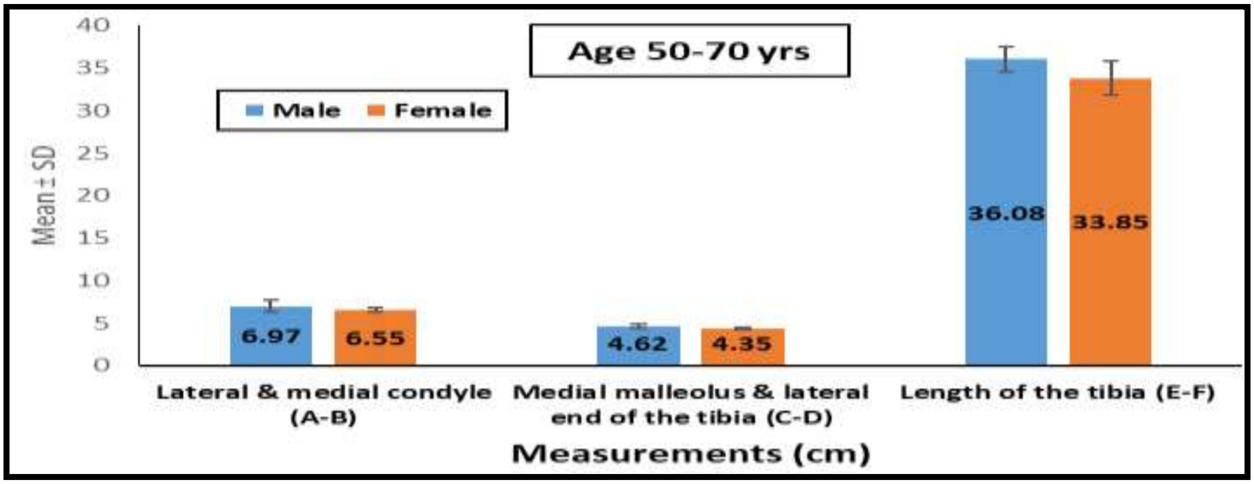

Fig. 4: Sex Distribution of Tibial Measurements Age Group [50-70 year]

As illustrated in **table 5 and Fig. 5,** the most accurate distance measurement was A-B [Lateral/medial condyle] 81.5% accuracy, followed by E-F distance [Medial malleolus & lateral end of the tibia] 76% accuracy, then C-D distance [Length of the tibia] 75% accuracy. Further, C-D distance was the most sensitive distance (83%), followed by A-B distance (70%), and then E-F distance was (63%). Also, A-B distance had the highest specificity (93%), followed by E-F distance (89%), and then C-D distance was (67%).

Table 5: Validity of Different Tibial Measurements for Sex Discrimination

	AUC	Cutoff	Sensitivity %	Specificity %	PPV	NPV	Accuracy	P-value
Lateral & medial condyle (A-B)	0.802	>6.9	70	93	90.9	75.6	81.5	**<0.001***
Medial malleolus/lateral end of the tibia (C-D)	0.828	>4.4	83	67	71.6	79.8	75	**<0.001***
Length of the tibia (E-F)	0.778	>36.6	63	89	85.1	70.6	76	**<0.001***

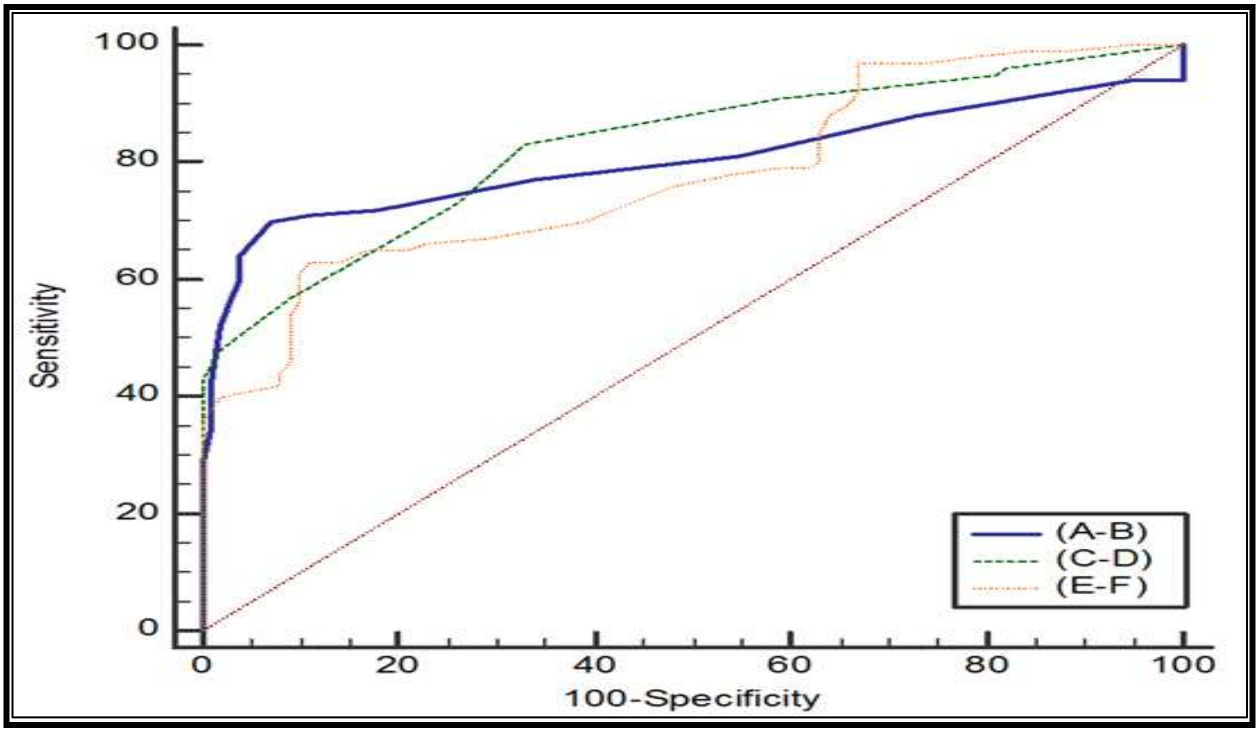

Fig. 5: ROC curve for different tibial measurements for sex discrimination

DISCUSSION

Rebuilding the biological profile—which includes determining sex, age, and stature—is crucial when unexplained skeletal remains are found **(19)**. Twenty-two percent of the body length is made up of the tibia. Because it is said to withstand erosion and retain its anatomical shape even after a lengthy period of burial, Tibia is frequently chosen by researchers **(20)**. Previous studies have demonstrated that tibial length enables more precise estimation of stature, which is why previous researchers chose it as the working material. Some research suggests that the tibia is the most accurate long bone to use when estimating stature **(21, 22)**.

The present study aimed to assess the efficacy of age and sex identification based on CT images derived from various tibial measurements among populations in Aswan. In this study, the mean age was 49.6 ± 10.1; 24% was in age group 30-40 years; 25% in 41-50 years; 37% in 50-60 years and 14% over 60 years.

In agreement, Karimi et al., (2019) investigated the morphometry of the proximal tibia in the standard resected surface of total knee arthroplasty in 132 patients, including 80 males (61%) and 52 females (39%) within the age range of 20-60 years; the mean age of the subjects was 38.26 ± 11.5 year **(23)**. Also, Diac et al., (2021) studied cases aged (22 to 91) years with a mean of 60.6 ± 16.4 **(24)**. Likely, in an Egyptian study by El-Meligy et al., (2006), the participants age was between 19 and 21 years **(25)**.

In this study, there was significant ($p<0.001$) difference between age ≤50 years and age >50 years according to different diameters (AB, CD and EF). In accordance with a study of Diac et al., (2021), there were significant differences between age and the height **(24)**. Also, López-Costas et al., (2012) examined the development of five tibial variables to assess their importance and potential for determining age and sex both during and after growth. Sexual significant differences were observed from age 15 onward, suggesting that these variables could be useful for sex determination in individuals older than 15 years. Strong correlation coefficients were identified between the five tibial variables and age **(26)**.

In the current study, the mean length of tibia in male was 37.1 ± 1.8 cm and 35 ± 1.9 cm in females. There was significant ($p<0.001$) difference between male and female according to different diameters (AB, CD and EF). Consistently, it was discovered that Malaysian men were taller than women in Ismail et al., (2018) study **(27)**. Likewise, in Italy, Gualdi-Russo et al., (2018) revealed that the average tibia length was higher ($p<0.001$) in males (40.2 ± 2.9 cm) compared with females (37.1 ± 2.7 cm) **(28)**. Males tend to be taller than females, which causes sex differences in adult linear bone measurements **(29)**. As a result, size normalization is required for sex comparisons **(30)**. Further, it was proposed that male bones are frequently bigger and stronger than female bones. It has also been demonstrated that females have smaller tibia morphology in relation to body size **(31)**.

The mean values of tibia measurements were higher in males than females in Nanayakkara et al., (2019) study in Sri Lanka. The results of this study clearly reaffirm that tibia is sexually dimorphic **(19)**. Gardasevic. (2019) examined standing stature in both Kosovan genders in the Western Region as well as its association with tibia length, as an alternative to estimating standing height. The mean of the standing height for male was 179.71 ± 5.9 cm and tibia length were 41.4 ± 3.1 cm, while for female the standing height was 166.3 ± 5.2 cm and tibia length were 37.6 ± 2.5 cm. The sex difference between standing height and tibia length measurements was significant ($p<0.001$) **(32)**.

In this study, validity of different tibial measurements for discrimination between male and female was as follows; (A-B) distance was the most accurate while C-D distance was the most sensitive and A-B distance was the most specific (93%). These results were in line with Akhlaghi et al., 2011 study who found that sex could be distinguished using the anthropometric parameters of the tibia; the lateromedial length with 90% sensitivity and 80% specificity, the medial length with 90% sensitivity and 85% specificity, the proximal width with 85% sensitivity and 87.5% specificity, and the distal width with 67.5% sensitivity and 75% specificity **(33)**. According to the findings of Nanayakkara et al., 2019, the prediction accuracies for determining sex utilizing tibial measurements ranged from 61.9% to 80.2% in the Sri Lankan population **(19)**. Also, Kranioti et al., 2017 study confirmed the existence of sexual dimorphism of the tibia. Furthermore, the study revealed the utility of tibia as a predictor of sex in Greek Cypriots and Cretans **(34)**. Similarly, Kranioti et al., 2017 analyzed the tibia in different populations of the southern Europe such as Greece, Italy, and Spain providing standards for sex estimation in a forensic context. All measurements were significantly different between the sexes in all three populations and in the pooled sample. A discriminant function of the pooled sample for Southern Europeans resulted in about 88 % accuracy using all three variables **(9)**.

CONCLUSION AND RECOMMENDATION

In conclusion, spiral CT of the proximal epiphysis of femur using the parameters previously mentioned (AB, CD and EF) distances which was identified by three points on tibia may be useful in sex identification which may be applied in cases in semi-fleshed or charred bodies. CT might be efficiently used as an alternative method applicable in certain circumstances. Our study had been carried out among Egyptian population, and so population specific aspects of sexual dimorphism must be taken in considerations when using this method, as there are population differences as mentioned before.

In recommendation, further consideration should be given to the comparison of ultrasonography and MRI 3D models to their physical counterpart. Other mathematical methods could be applicable in future research in the field of forensic anthropology bone fragments as well as with whole skeletons. Wide application of CT scan to be done in sex identification and in forensic practice. Further studies to compare results obtained from CT scan when used for determination of sex from bones and the results obtained from using MRI and plain X-ray.

Study Limitations

There were some limitations to the current study. Firstly, this was a single-center study which limits the study's external validity (generalization). Secondly, the possible confounding factors (presence of alloimmunization, platelet refractoriness, etc.) were not accounted for to do matching between groups.

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