THE ACCURACY OF THE ANTHROPOMETRIC MEASUREMENTS OF KNEE BONES IN DETERMINATION OF AGE AND SEX IN AN EGYPTIAN POPULATION SAMPLE.

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ABSTRACT

Identification of age and sex are considered the cornerstone in biological profile determination in forensic anthropology. **AIM OF THE STUDY:** To establish a comparative evaluation of the accuracy of some knee bone measurements in sex and age discrimination. **METHODS:** The anthropometric measurements of knee bones were obtained from Magnetic resonance imaging (MRI) scans of patients in Kasr Elainy school of medicine. Discriminant function analysis is used for sex discrimination by using three measurements of the patella and three measurements of both distal femur & proximal tibia. **RESULTS:** Both distal femur & proximal tibia measurements were more accurate for sex differentiation. A six novel cutoff values were obtained by Roc curve for sex identification. Patella anteroposterior length showed a significant negative correlation with age by conducting a novel regression equation for age estimation. **CONCLUSION:** Measuring the patella and both distal femur & proximal tibia dimensions by the MRI scan can be efficient for sex discrimination with more accuracy in both distal femur & proximal tibia dimensions.

Keywords

Sex and age determination, Anthropology, Patella, Femur, Tibia

INTRODUCTION

The most essential step in personal identification is the determination of sex, age, race, and stature **(Teke et al., 2018)**. Determining the sex is the first essential step for biological or skeletal identification and can help in both criminal and civil situations. Information about stature and weight, depends on sex identification **(Derya et al., 2019).**

To do so, the availability of a complete skeleton or parts of the skeleton such as the pelvic bones or skull, is essential for identification; however, incomplete human remains are often found in case of mass disasters. Moreover, these skeleton parts are more liable to damage because of its spongy nature and low tissue density. So, using bones with more resistance to postmortem changes is more efficient **(Rahmani et al., 2020)**.

The growth of forensic anthropology and forensic radiology has led to the use of a variety of techniques for the analysis of anthropometric features of the bones. These techniques aid in the visualization and precise measurement of the bone elements on bodies during autopsies, on skeletal remains following exhumation, as well as on living individuals. **(Marinković et al., 2021).**

The accuracy of the morphological methods depends on observer experience, but metric methods objectively validate results. Discriminant function analysis is the most common method used for sex estimation however, it's a population-specific method. Equations of discriminant function for sex identification are population-specific, therefore requiring their development for each population **(Rahmani et al., 2020; Peckmann et al., 2016).**

The utilization of various bones of the skeletal system has been made possible by modern radiological procedures. As a result, radiological examination of the knee can be used to investigate the anthropometric traits of the distal femur and proximal tibia. So far, several sex-specific anthropometric characteristics of the distal femur and proximal tibia have been discovered **(Marinković et al., 2021).**

Moreover, the patella, a flat bone in the front of the knee joint and the biggest sesamoid bone in the human body, serves to protect the knee joint. Due to the patella's high density, it can survive post-mortem alterations and be used to identify the sex of unidentified human remains **(Peckmann et al., 2016).**

The study aims to affirm the reliability of patella and both distal femur & proximal tibia anthropometric measurements for estimating sex and age of a sample of the Egyptian population using Magnetic resonance imaging (MRI) scans and to establish a comparative evaluation of their accuracy in sex and age discrimination.

SUBJECTS AND METHODS

The current work is a cross sectional analytical study. It's carried out through the cooperation between the Forensic Medicine and Clinical Toxicology department, and the Department of Radiology, Cairo University School of Medicine, Egypt. The study was performed after the approval of Cairo University's Faculty of Medicine's ethical committee (**N-46-2023).**

STUDY DESIGN

MRI scans were taken from 207 Egyptian living hospital patients (116 males and 87 females) aged between 30-50 years during the examination of patients' knees throughout clinical evaluations and diagnostic procedures for a variety of various painful knee conditions. Patients with history of previous surgery, knee fracture due to trauma, patellar bipartite variant, metabolic disorders, nutritional disorders, posttraumatic arthritis with an intra-articular fracture, or severe rheumatoid arthritis were excluded from this study as that would render measurements inaccurate. MRIs with poor resolution were also excluded.

Diagnostic MRI examinations were done using the **Philips 1.5 T** while the analyses included three bones; the patella, the distal part of the femur, and the proximal part of the tibia. The diameters were measured during the anteroposterior examination in line with anteroposterior measurement standards.

The distal part of the femur and the proximal part of the tibia are measured and coded as shown in Figure (1):

- The mediolateral diameter of the distal femur condyle **(MLF).**
- The mediolateral diameter of the proximal tibia condyle **(MLT).**
- The diameter of the Proximal tibia intercondylar eminence **(PTIE).**

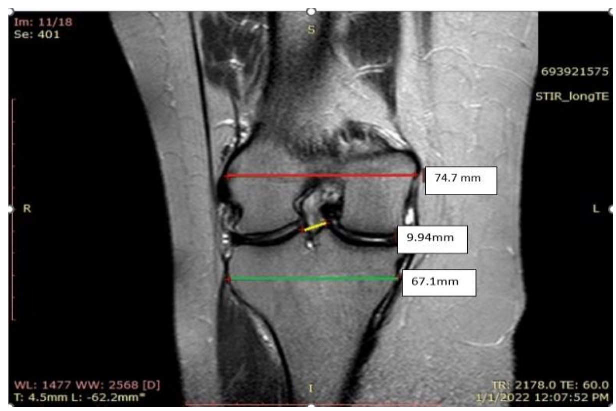

Figure (1): The distal femur and the proximal tibial measurements; the red line: Mediolateral of the distal femur condyle (MLF), The yellow line: Diameter of the proximal tibia intercondylar eminence condyle (PTIE)and The green line: Mediolateral of the proximal tibia condyle (MLT)

Three patellar parameters were measured as shown in Figure (2) and **Figure (3) and coded as follow:**

- Transverse length of patella **(TLP),** which is the entire distance between the medial and lateral facet's lateral edges.
- The patella's overall length from superior to inferior, or craniocaudal length of patella **(CCLP).**
- A vertical line was drawn on the midline anterior starting at the interfacet point to measure the anterior-posterior length of the patella **(APLP).**

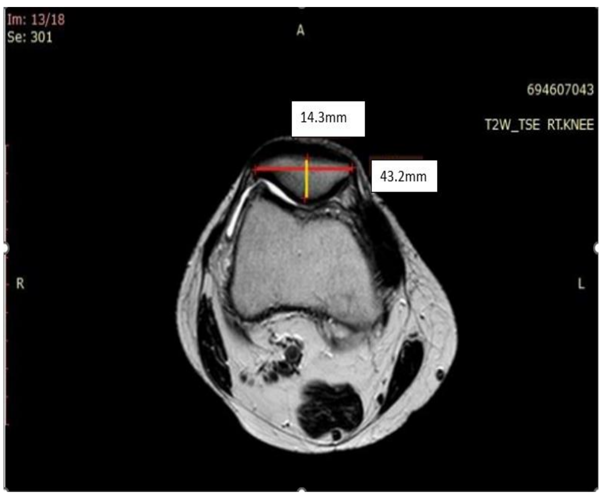

Figure (2): Axial plane showing Patella measurements; yellow line: Anteroposterior length of the patella (APLP) and Red line: Transverse length of the patella (TLP).

Figure (3): Sagittal plane showing Craniocaudal lenght of the patella (CCLP)

All the measurements were measured in millimeter (mm).

SAMPLE SIZE

- 0.05 alpha error, 0.95 confidence interval, and 0.80 power of the study were entered into the PASS 11 sample size calculator to determine the minimal sample size required to investigate the reliability of the patellar, distal femoral, and proximal tibial anthropometric measurements in sex and age identification in an Egyptian population sample.
- The total sample size calculated is 202 Egyptian Persons from both sexes.

STATISTICAL ANALYSIS

The data were coded and entered using SPSS, the statistical software for the social sciences (SPSS), version 28 (IBM Corp., Armonk, NY, USA). For quantitative variables, the mean, standard deviation, minimum and maximum, and frequencies (number of occurrences), and relative frequencies (percentages), were used to summarize the data. The comparisons between males and females were made using the unpaired t-test **(Chan et al., 2003a).** The relationships between the quantitative variables were calculated using the Pearson correlation coefficient **(Chan et al., 2003b).** Age was predicted using significant measurement and linear regression analysis **(Chan et al., 2004).** The test for mean equality between males and females was the first step in the discriminant analysis. The significant predictors required to establish the discriminate function were identified using stepwise statistics. Then, group centroids (group means) were determined, representing the decisive points for discriminating between men and women. It was done to categorize the percentage of cases that were correctly categorized using the discriminate function **(Chan et al., 2005).** The ideal cutoff value of the parameters for the detection of males was discovered using the area under curve analysis and the construction of the ROC curve. Statistics were considered significant for P-values under 0.05.

RESULTS

The studied population's mean age was 39.58 years. The mean values of TLP, APLP, and CCLP in all subjects were 43.08 mm, 19.55 mm, and 40.86mcm respectively, while the mean MLF, MLT and PTIE were (78.73) mm, (71.24) mm, and (11.75) mm respectively as demonstrated in **(Table 1).**

Table (1): The Mean and the standard deviation of the subjects' age and the measured parameters.

	Mean (mm)	Standard Deviation	Minimum (mm)	Maximum (mm)
Age	39.58	6.66	30.00	57.00
TLP	43.08	4.24	31.00	54.00
APLP	19.55	2.75	10.00	37.00
CCLP	40.86	5.05	17.00	54.00
MLF	78.73	6.39	65.00	95.00
MLT	71.24	6.25	57.00	85.00
PTIE	11.75	1.54	6.00	18.00

Patella transverse length (TLP), Mediolateral diameter of the distal femur condyle (MLF)Patella anteroposterior length (APLP) Mediolateral diameter of the proximal tibia condyle (MLT), Patella craniocaudal length (CCLP) Proximal tibia intercondylar eminence (PTIE)

There were statistically significant higher values for males than females in the three measurements of the patella and three measurements of the distal femur & proximal tibia with ($p < 0.001$) **(Table 2).**

Univariate Discriminant Function Analysis was done for each measurement separately with concluding a discriminant score, which is estimated by multiplying each variable by its corresponding coefficient and then adding the resultant value to a constant; considering that negative scores are classified as females and positive scores are classified as males, and we were able to obtain six equations to identify sex from each measurement as follows:

- **TLP Function**= -12.506+0.290* TLP, properly classifying 77.3% of the initial grouped cases.
- **APLP Function=-**7.656+0.392* APLP, properly classifying 71.9% of the initial grouped cases.
- **CCLP Function**=-9.700+0.237* CCLP, accurately classifying 74.4% of the initial grouped instances.
- **MLF:** 90.6% of the initially grouped cases were correctly classified (Function=-20.221+0.257* MLF).
- **MLT Function=-**16.825+0.236* MLT, accurately classifying 90.1% of the initial grouped cases.
- **PTIE Function=-**9.500+0.809* PTIE, accurately classifying 77.8% of the initial grouped cases.

When it comes to patella measurements, the TLP is the most sexually dimorphic measurement with 77.3% accuracy, while APLP showed the least accuracy (71.9%). When it comes to measurements of the distal part of the femur and the proximal part of the tibia, the MLF was the most sexually dimorphic measurement with 90.6% accuracy, followed by the MLT with 90.1% accuracy, while PTIE showed the least accuracy (77.8%). The distal femur and proximal tibia measurements were shown to be more accurate for sex distinction than the patella measurements by univariate discriminant analysis.

Table (2): Sexual dimorphism of the patella, distal femur & proximal tibia measurements of studied sample.

	Sex								P value
	female				Male				
	Mean (mm)	SD	Minimum (mm)	Maximum (mm)	Mean (mm)	SD	Minimum (mm)	Maximum (mm)	
TLP	40.22	3.28	31.00	48.00	45.23	3.56	35.00	54.00	<0.001
APLP	18.34	2.84	10.00	37.00	20.45	2.32	10.00	26.00	<0.001
CCLP	37.62	3.90	17.00	45.00	43.28	4.43	33.00	54.00	<0.001
MLF	72.89	3.63	65.00	83.00	83.12	4.08	73.00	95.00	<0.001
MLT	65.93	4.27	57.00	85.00	75.22	4.21	57.00	84.00	<0.001
PTIE	10.69	1.23	6.00	13.00	12.54	1.24	10.00	18.00	<0.001

Patella transverse length (TLP), Mediolateral diameter of the distal femur condyle (MLF), Patella anteroposterior length (APLP), Mediolateral diameter of the proximal tibia condyle (MLT), Patella craniocaudal length (CCLP), Proximal tibia intercondylar eminence (PTIE)

For the direct and stepwise multivariate discriminant function equations derived from the Egyptian population, **Tables (3)** displays the discriminant function coefficients and group centroids. The following were the discriminant functions that the stepwise discriminant analysis yielded:

Discriminant Score by patella measurements stepwise model =

(− 12.627) + 0.187 * TLP + 0.112* CCLP.

- **Discriminant Score by both distal femur & proximal tibia measurements stepwise model** = (-20.154-) + 0.233* MLF + 0.157* PTIE.
- **Discriminant Score by patella and both distal femur & proximal tibia measurements stepwise model**= (-20.154-) + 0.233* MLF + 0.157* PTIE.

The accuracy rates of sex determination are estimated by multivariate direct and stepwise Discriminant Function Analysis are shown in **Table (4).** The estimated accuracy of the patella measurements was 81.0% for males, 73.6% for females, and 77.8% of the total when the three patella measurements and the three measurements of both the distal part of the femur and the proximal part of the tibia were entered into the analysis model (Enter Independents Together). The measurements for both the distal femur and proximal tibia were 90.5% for males, 93.1%.

TLP and CCLP measures were chosen for the discriminant function, according to the results of a stepwise discriminant function analysis. While the MLF and the PTIE were chosen for the discriminant function of both distal femur& proximal tibia measurements with 91.6% overall accuracy of patella and both distal femur& proximal tibia measurements, the accuracy rates for males, females, and the total in sex estimation are 82.8%, 73.6%, and 78.8%% respectively.

Table (3): Direct and stepwise discriminant function coefficients and group centroids for sex differentiation using the patella and both distal femur& proximal tibia measurements and a combination of both.

			Unstandardized coefficients	Standardized coefficients	Centroids	
					Female	Male
Patella measurements	Enter	TLP	0.150	0.516	-0.917-	0.688
		APLP	0.088	0.226		
		CCLP	0.118	0.497		
		(Constant)	-12.995-			
	Stepwise	TLP	0.187	0.645	-0.898-	0.673
		CCLP	0.112	0.470		
		(Constant)	-12.627-			
Distal femur& proximal tibia measurements	Enter	MLF	0.194	0.756	-1.543	1.157
		MLT	0.050	0.210		
		PTIE	0.136	0.169		
		(Constant)	-20.419-			
	Stepwise	MLF	0.233	0.905	-1.526-	1.145
		PTIE	0.157	0.194		
		(Constant)	-20.154-			
Patella and both distal femur& proximal tibia measurements	Enter	TLP	0.003	0.009	-1.545-	1.159
		APLP	0.006	0.015		
		CCLP	0.013	0.055		
		MLF	0.185	0.719		
		MLT	0.049	0.208		
		PTIE	0.140	0.173		
		(Constant)	-20.439-			
	Stepwise	MLF	0.233	0.905	-1.526-	1.145
		PTIE	0.157	0.194		
		(Constant)	-20.154-			

Patella transverse length (TLP), Mediolateral diameter of the distal femur condyle (MLF), Patella anteroposterior length (APLP), Mediolateral diameter of the proximal tibia condyle (MLT), Patella craniocaudal length (CCLP), Proximal tibia intercondylar eminence (PTIE)

Table (4): Classification accuracy for sex differentiation using the patella and both distal femur& proximal tibia measurements and a combination of both.

Model			Female (87)		Male (116)		Overall accuracy (%)
			N	%	N	%	
Patella measurements	**Enter**	**Original**	64	73.6	94	81.0	77.8%
		Cross-validated	64	73.6	92	79.3	76.8%
	Stepwise	**Original**	64	73.6	96	82.8	78.8%
		Cross-validated	62	71.3	96	82.8	77.8%
Both distal femur& proximal tibia measurements	**Enter**	**Original**	81	93.1	105	90.5	91.6%
		Cross-validated	81	93.1	105	90.5	91.6%
	Stepwise	**Original**	81	93.1	105	90.5	91.6%
		Cross-validated	81	93.1	105	90.5	91.6%
Patella and both distal femur& proximal tibia measurements	**Enter**	**Original**	81	93.1	105	90.5	91.6%
		Cross-validated	81	93.1	104	89.7	91.1%
	Stepwise	**Original**	81	93.1	105	90.5	91.6%
		Cross-validated	81	93.1	105	90.5	91.6%

Table (5) & figure (4) show cut-off values to differentiate between males and females by patella and both distal femur& proximal tibia measurements using the Roc curve, and we were able to obtain **six novel cut-off values** which are (43.5, 18.5, 41.5, 76.5, 69.5 & 11.5) for TLP, CCLP, APLP, MLF, MLT, PTIE respectively, with significant values and the highest measurement with the highest sensitivity was the MLT (94.8%) while the measurement with the highest specificity was the MLF (89.7%).

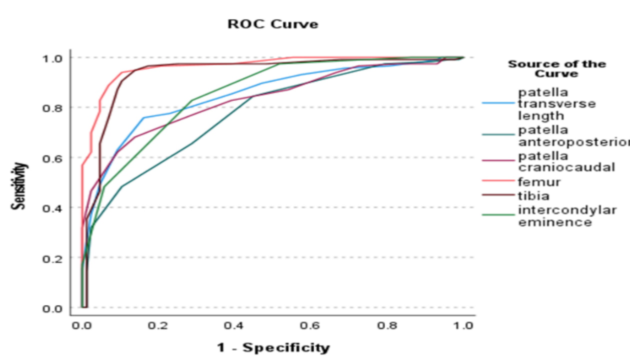

Figure (4): ROC curve for detection of the cutoff value for differentiating sex based on the patella and both distal femur& proximal tibia measurements

Table (5): Cutoff value between males and females from the patella and both distal femur& proximal tibia measurements

	Area Under the Curve	P-value	95% Confidence Interval		Cut off	Sensitivity %	Specificity %
			Lower Bound	Upper Bound			
TLP	0.850	< 0.001	0.798	0.902	43.5	75.9	83.9
APLP	0.777	< 0.001	0.714	0.840	18.5	84.5	55.2
CCLP	0.833	< 0.001	0.779	0.888	41.5	68.1	86.2
MLF	0.966	< 0.001	0.944	0.988	76.5	94	89.7
MLT	0.937	< 0.001	0.899	0.976	69.5	94.8	86.2
PTIE	0.855	< 0.001	0.804	0.906	11.5	82.8	71.3

Patella transverse length (TLP), Mediolateral diameter of the distal femur condyle (MLF), Patella anteroposterior length (APLP), Mediolateral diameter of the proximal tibia condyle (MLT), Patella craniocaudal length (CCLP), Proximal tibia intercondylar eminence (PTIE)

Table (6): Correlation of patella, distal femur & proximal tibia measurements with the age of the studied samples

	AGE		
	R	P value	N
TLP	-0.065-	0.358	203
APLP	-0.157-	0.025	203
CCLP	-0.105-	0.137	203
MLF	-0.122-	0.083	203
MLT	-0.134-	0.057	203
PTIE	-0.095-	0.178	203

Patella transverse length (TLP), Mediolateral diameter of the distal femur condyle (MLF), Patella anteroposterior length (APLP), Mediolateral diameter of the proximal tibia condyle (MLT), Patella craniocaudal length (CCLP), Proximal tibia intercondylar eminence (PTIE)

Table (6) shows a statistically significant negative relation between the age and the APLP (P value= 0.025) as a decrease in the APLP accompanies increasing age, while other measurements showed no significant negative correlation with age.

The estimation of age from APLP is calculated through the linear regression equation where age equals the multiplication product of the APLP with its corresponding coefficient and subtracting the resultant value from the constant, as follows: Age=47.022-0.381* APLP.

DISCUSSION

Determination of sex and age from the human skeleton is a crucial task in the field of forensic anthropology for human identification **(Aly et al., 2016).** Therefore, our study was carried out to detect the reliability of patella, distal femur & proximal tibia measurements in sex and age determination in a sample of the Egyptian population as well as compare their accuracy.

As regards sex identification from the three studied measurements of the patella, a significant difference between both sexes was noted. By using the Roc curve, we were able to obtain **three novel cut-off values** which are 43.5, 18.5 & 41.5 for TLP, APLP, CCLP respectively, where higher values are more likely to be of male origin, and lower values are more likely to be of female origin.

By using univariate discriminant analysis, TLP was found to be the most significant measurement of the patella bone for sex differentiation with 77.3% accuracy, followed by the CCLP with 74.4% accuracy, while APLP showed the least accuracy (71.9%). Multivariate stepwise discriminant function analysis, which included only TLP, and CCLP concluded accuracy rates of 82.8%, 73.6%, and 78.8% for males, females, and the whole sample, respectively.

The sexual dimorphism of patella measurements was studied in different populations with similar reported conclusions. As for the Iranian population, **Rahmani et al. (2020)** concluded that the patellar accuracy in sex determination was 84.5% for TLP, 75.2% for CCLP, and 65.8% for TLP. The stepwise multivariate discriminant analysis included the measurement of the maximum TLP and maximum CCLP with an accuracy of 85.7%. In 2010, **Akhlagi et al.** performed a study on direct patella measurements of 113 (57 males, 56 females) Iranian cadavers with 92.9% accuracy for sex discrimination.

A sample of the Turkish population studied by **Teke et al. (2018)** consisting of 220 subjects whose patellae were measured using knee MRI images with accuracy 91% and 87% for females and males respectively by multivariate discriminant analysis. They also noted that the TLP had the highest accuracy for sex identification through univariate discriminant analysis.

Regarding the Spanish population, six patellar parameters, including maximum length, maximum width, and maximum thickness, were measured on 106 individuals by **Peckmann et al. (2016),** who noted that all parameters were sexually dimorphic with overall accuracy ranging from 75.2% to 84.8%.

As for sex discrimination from the measured parameters of the distal femur & proximal tibia, it was noted that males have higher mean values than females with concluding **three novel cut-off values** which are 76.5, 69.5 & 11.5 for the MLF, MLT and PTIE, respectively. Higher values are more likely to be classified as males. In contrast, lower values are more likely to be classified as females.

Furthermore, the univariate discriminant analysis showed the MLF as the most sexually dimorphic both distal femur& proximal tibia measurements have 90.6% accuracy followed by MLT with 90.1% accuracy, while PTIE was the least accurate (77.8%). Multivariate stepwise discriminant function analysis, which included only MLF and PTIE, concluded overall accuracy of 90.5%, 93.1%, & 91.6% for males, females, and the whole sample, respectively.

Among the Turkish population and in a study presented by **Gulhan et al. (2015)** and included thirteen femur parameters, it was noted that femoral bicondylar breadth is one of the parameters with the highest accuracy, representing 86.5% for sex diagnosis. After that, and in **2016, Ekizoglu et al.** performed a study on CT images of seven tibia parameters, and the upper epiphyseal breadth was found to be the best single parameter for sex differentiation with an accuracy of 86%.

Similar conclusions were noted in different populations as the Korean population **(Lim et al., 2013),** Chinese and Caucasian populations **(Li et al., 2014),** African American, East Asian, and Caucasian **(Mahfouz et al., 2012),** where males are having significant higher bony dimensions than females as regard MLF, MLT. Furthermore, the last two studies above revealed significant ethnic-related differences regarding the parameters studied.

Added to the two parameters mentioned above, and recently in **2021, Marinković et al.** noted sex-related differences in PTIE.

In the present study, a comparison between the accuracy of the patella measurements and both distal femur& proximal tibia measurements in sex identification was done and revealed that the latter was more accurate for sex differentiation compared with the patella measurements using univariate and multivariate direct and stepwise discriminant analysis, and using the combined measurements of patella, femur, and tibia has no superiority over using only the femur and tibia measurements because of the same resulted value of accuracy (91.6%).

Regarding age identification, all studied parameters showed no significant negative correlation with age except for APLP, which showed a significant negative correlation with age with conducting a new regression equation for age estimation. The negative correlations indicate decreasing bony dimensions that may attribute to age-related bone loss, which involves a gradual decrease in bone mineral density with age (**Demontiero et al., 2012**).

To the best of our knowledge, this is the first study to investigate those combined parameters, the patella, distal femur, and proximal tibia, for sex and age identification in the Egyptian population. Nevertheless, the results were in harmony with other studies on different populations, with some expected differences attributed to ethnic-related traits and diversity in the age, sample size, and used methodologies. So, it is recommended to conduct further studies on different populations and anatomical regions.

CONCLUSION

MRI measurements of patella and both distal femur & proximal tibia dimensions proved to be efficient for sex discrimination among the Egyptian population with more accuracy in both distal femur & proximal tibia dimensions.

COMPLIANCE WITH ETHICAL STANDARDS

- **Funding:** the authors did not receive support from any organization for the submitted work
- **Disclosure of potential conflicts of interest: t**he authors have no relevant financial or non-financial interests to disclose
- **Ethical approval:** the study was performed after the approval of Cairo University's Faculty of Medicine's ethical committee. The ethical approval number is **N-46-2023.**
- **Informed consent:** informed consent was obtained from all individual participants included in the study.
- **Data Availability Statements:** the datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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الملخص العربي

دقة القياسات البشرية لعظام الركبة في تحديد العمر والجنس في عينة من المصريين

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يعتبر تحديد العمر والجنس حجر الزاوية في تحديد السمات البيولوجية في أنثروبولوجيا الطب الشرعي. **الهدف من الدراسة:** إنشاء تقييم مقارنة دقة بعض قياسات عظام الركبة في تمييز الجنس والعمر. **طريقة الدراسة**: تم الحصول على القياسات البشرية لعظام الركبة عن طريق الرنين المغناطيسي للمرضى في كلية طب قصر العيني.تم استخدام تحليل الوظيفة التميزيية باستخدام ثلاثة قياسات للرضفة وثلاثة قياسات لكل من الجزء السفلي من عظمة الفخذ والجزء العلوي من عظمة القصبة. **النتائج:** كانت قياسات الجزء السفلي من عظمة الفخذ والجزء العلوي من عظمة القصبة أكثر دقة للتمييز بين الجنسين. تم الحصول على ستة قيم قطع جديدة من خلال منحنى Roc لتحديد الجنس .أظهر طول الرضفة الأمامية الخلفية ارتباطًا سلبيًا مع العمر من خلال إجراء معادلة انحدار جديدة لتقدير العمر. **الخلاصة**: يمكن أن يكون قياس الرضفة وأبعاد الجزء السفلي من عظمة الفخذ والجزء العلوي من عظمة القصبة عن طريق الرنين المغناطيسي فعالاً للتمييز بين الجنسين بدقة أكبر في كل من أبعاد الجزء السفلي من عظمة الفخذ والجزء العلوي من عظمة القصبة.