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Sex Determination from the Patella in a Thai Population

Determinación del Sexo a Partir de la Rótula en una Población Tailandesa

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SUMMARY: The aim of this study was to derive the equations for sex determination and to test the accuracy of discrimination between sexes using measurements of the patella in the Thai population. The sample comprised 254 Thai skeletons (134 males and 120 females) aged between 22 and 97 years, with an average age of 63.3years, obtained from the Osteology Research and Training Center, Faculty of Medicine, Chiang Mai University, Chiang Mai. Six variables were measured in 254 pairs of normal patellae. The mean values of patellar measurements in males were significantly greater than those in females for all variables (P<0.05). Statistical analysis further showed that all variables were useful in sex determination. Stepwise discriminant function analysis yielded an accuracy of 83.2 % (83.8 % male, 82.5 % female) and 85.5 % (85.3 % male, 85.8 % female) for the left and right patellae, respectively. These results suggested that measurement of the right patella is preferable for skeletal sexing. If this is not available, the forensic specialist can use the left patella instead, with an average accuracy of more than 80.0 % in giving a correct classification. The findings of this study demonstrate that the patella is an important bone in sex determination. They suggest that either the left or right patella can be used for sex determination, especially in the Northern Thai population.

KEY WORDS: Forensic anthropology; Sex determination; Patella; Thai population.

INTRODUCTION

The biological identification of an individual based on skeletal remains is one of the most important aspects of forensic science and forensic anthropology. An individual's biological profile consists of sex, ancestry, age at death, and stature (Austin & King, 2016). Determining the sex of an individual is the first step in establishing the identity of any human remains, particularly in forensic circumstances, since it can decrease the possibility of misidentification by 50 % (Phenice *et al*., 1969; Krogman & Iscan, 1986).

In previous studies, sex determination based on bones has been accomplished by the use of either non-metric or metric methods. Non-metric methods are considered to be useful for observing differences in the gross morphological features between males and females in relation to hormones and muscle mass (EI-Najjar *et al*., 1978). For example, the pelvis and skull are widely used (Hoshi *et al*., 1962; Rogers & Saunders, 1994), particularly when employing morphological methods. The pelvis is the most useful part of the skeleton when determining sex, with an average accuracy rate of 95 %, followed by the skull, which has an average accuracy rate of 92 % (Phenice *et al*., 1969; Meindl *et al*., 1985). However several studies have reported significant differences in the individual bones of various populations. Therefore, all discriminant function equations for sex determination derived from discriminant analyses are population-specific (Knussmann & Sperwien, 1988). The metric method for estimating the sex of skeletal remains is considered to be more objective and is highly valued in court testimonies. It is a standardized and statistically approved method characterized by low error rates (DiGangin & Moore, 2013). These measurements can be performed and applied to whatever portions of a skeleton are available in an appropriate condition. However, the degree of accuracy differs, depending on the individual bones used to classify the sex. If the pelvic bone and skull, which are common choices for determining sex in non-metric methods, are unavailable or if the other bones used for measurement methods are damaged or absent, it is important to establish methods for sex estimation based on other parts of the skeleton. The patella is one such bone for which metric methods can be used to ascertain an individual's sex with a high degree of accuracy (Peckmann *et al*., 2016).

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The patella plays a protective role by reducing contact between the quadriceps tendon and the femur, minimizing frictional forces. It also acts as a safeguard for the deeper structures in the knee joint, functioning as a bony shield (Cox *et al*., 2023). The patella exhibits high resistance to postmortem alterations, making it a useful indicator in determining the sex of an individual during human skeletal identification (Peckmann *et al*., 2016).

The patella has recently been used as a metric technique for sex identification across numerous populations. Since previous studies were conducted on samples from different populations, there is still a need for developing population-specific criteria (Duric *et al*., 2005). The results of sex determination obtained from a limited sample or a specific population are not suitable for making comparisons across different populations (Spradley *et al*., 2008), due to the strong influence of genetic and environmental elements on skeletal development.

In Thailand, metric methods for sex determination have been developed for several parts of the skeleton. However, there has been little research on sex determination using the patella, therefore, the present study aims to derive the equations for sex estimation using the patella and to test the accuracy of the discrimination function in the Thai population.

MATERIAL AND METHOD

The present study was conducted with the approval of the Research Ethics Committee, Faculty of Medicine, Chiang Mai University, Thailand (No 7681/2020) and the University of Phayao Human Ethics Committee, Phayao, Thailand (No. 1.1/029/63). The sample consisted of 254 individuals (134 males, 120 females) from a Thai population obtained from the Osteology Research and Training Center, Faculty of Medicine, Chiang Mai University, Thailand. The age at death was between 22 and 97 years, with a mean average age of 63.3 years. The ages for males ranged from 28 to 97 years, and the mean age of the male sample was 62.8 years with a standard deviation (SD) of 14.4 years; the ages of the females ranged from 22 to 94 years, and the mean age of the female sample was 64.0 years with an SD of 16.2 years.

The study used both sides of the patellae. The Thais in the sample were included in a database incorporating death certificates that showed the sex, year of birth, and age at death. Patellae exhibiting fractures, trauma, damage, or bone pathology were excluded from the study.

The techniques and the abbreviations for all the variables in this study were adapted from (Bidmos *et al*., 2005) and include an indication of the side (L for the left side and R for the right side). Six variables on both sides of the patellae were measured to the nearest 0.01 mm using a digital sliding vernier caliper (Mitutoyo, São Paulo, Brazil). These measurements consisted of (1) maximum height (MAXH), (2) maximum breadth (MAXB), (3) maximum thickness (MAXT), (4) lateral articular facet breadth (LAFB), (5) height of articular facet (HAF), (6) medial articular facet breadth (MAFB) shown in the Figure 1.

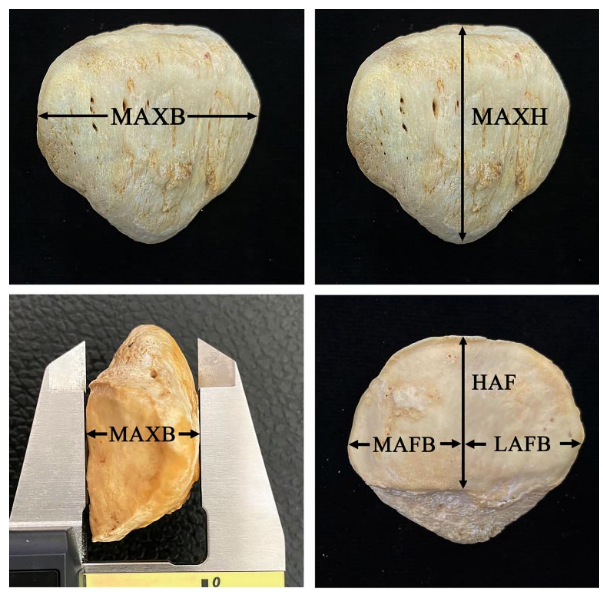

Fig. 1. Patellar measurement: MAXH, maximum height; MAXB, maximum breadth; MAXT, maximum thickness; LAFB, lateral articular facet breadth; HAF, height of articular facet; MAFB, Medial articular facet breadth.

Table I. Description of measurements and abbreviation of variables for the patella.

Measurements	Abbr.	Descriptions
1) Maximum height	MAXH	Direct maximum distance between the base and the tip of apex.
2) Maximum breadth	MAXB	Direct maximum distance between the medial and the lateral surfaces.
3) Maximum thickness	MAXT	Maximum distance between the anterior and the posterior surfaces.
4) Lateral articular facet breadth	LAFB	Distance between the lateral edge of the patella and the median ridge (vertical ridge) of the articular facet.
5) Height of articular facet	HAF	Maximum height distance between the most superior and the most inferior point of articular facet on the posterior surface.
6) Medial articular facet breadth	MAFB	Distance between the medial edge of the patella and the median ridge (vertical ridge) of the articular facet.

Each variable was measured non-consecutively three times and the averages of the three numbers for each measurement for each individual were recorded. Details of each variable are shown in Table I and Figure 1.

Statistical analysis. Discriminant analysis was conducted to analyze all of the data collected. The intraclass correlation coefficient (ICC) was used to determine intra-observer and inter-observer agreement using 30 randomly selected patellae (15 males, 15 females) for each measurement variable. There were two observers in each intra-observer and inter-observer team, and the measurements were made one week apart. The data were analyzed using the IBM SPSS statistics version 26 software program with a significance level of 0.05. Descriptive statistics, such as the mean, the SD, the minimum and the maximum, were obtained for all the variables. The normality of the data was assessed, and a paired t-test was conducted for the data being analyzed. The measurements were divided into male and female groups to ensure the accurate representation of each sex.

RESULTS

The ICC consisted of the averages of the intra-observer and the inter-observer error rates for all of the measurements. The results showed that the intra-observer consistency was greater than 0.85, which was considered excellent. The results for the inter-observer error range were between 0.89 and 0.94, which indicated high reliability, while all of the comparisons between the original measurements and the repeat measurements indicated that there were no significant differences (P>0.05) among the six variables.

Descriptive statistics were determined for the mean, standard deviation (SD) and standard error of the mean (SE). A Student's t-test was used to compare all variables between males and females. As shown in Table II, there was a significant population difference (P< 0.05). Based on the results of the Student's t-test, it was found that the average patella measurements for males were greater than those for females (P< 0.05). This suggests that most of these measurements could be used as indicators of sex.

Table III. Description statistics of both sides left and right patellar measurement in male and female patella with % average accuracy of each individual variable function analysis.

Variable	t	P-value	% Average accuracy
1. MAXH (R)	10.849	0.000	75.8%
2. MAXB (R)	12.801	0.000	78.9%
3. MAXT (R)	10.069	0.000	74.2%
4. LAFB (R)	11.846	0.000	74.2%
5. HAF (R)	8.723	0.000	70.7%
6. MAFB (R)	9.757	0.000	76.6%
7. MAXH (L)	12.722	0.000	79.7%
8. MAXB (L)	12.347	0.000	76.2%
9. MAXT (L)	10.451	0.000	73.0%
10. LAFB (L)	11.862	0.000	76.6%
11. HAF (L)	9.813	0.000	72.7%
12. MAFB (L)	10.845	0.000	75.0%

*All Significant at (P< 0.05).

Table III shows the description statistics of both sides of the left and right patellar measurements in male and female patellae with the percentage average accuracy of each variable in discriminant function analysis. From univariate discriminant function analysis, all variables can be used to determine sex. The average accuracy of all variables of both sides of the left and right patellae was more than 70 %, ranging from 70.7 to 79.7 %.

Table IV shows the stepwise discriminant functions performed for all 6 available measurements. Function 1

Table II. Descriptive statistic of both sides left and right patellar measurement in male and female.

Variable	Male (n=134)					Female (n=120)				
	Min	Max	Mean	SD	SE	Min	Max	Mean	SD	SE
Age (Years)	28	97	62.790	14.432	1.238	22	94	64.030	16.281	1.486
1.MAXH (R)	30.98	50.1	41.125	3.114	0.267	28.74	45.03	37.102	2.777	0.253
2. MAXB (R)	37.5	51.45	44.412	2.902	0.249	33.32	45.94	40.093	2.438	0.223
3. MAXT (R)	17.02	24.82	20.897	1.568	0.134	16.4	21.93	19.097	1.250	0.114
4. LAFB (R)	20.11	30.55	26.587	1.659	0.142	20.11	28.15	24.086	1.715	0.157
5. HAF (R)	23.93	36.30	30.383	2.496	0.214	21.61	33.87	27.909	2.038	0.186
6. MAFB (R)	15.21	25.16	21.094	1.849	0.159	14.91	25.44	18.756	1.983	0.181
7. MAXH (L)	28.90	50.14	41.370	3.043	0.261	28.47	43.70	36.752	2.726	0.249
8. MAXB (L)	37.18	50.57	44.161	2.847	0.244	33.15	45.62	39.949	2.576	0.235
9. MAXT (L)	16.49	24.95	20.861	1.625	0.139	15.97	21.78	19.006	1.203	0.110
10. LAFB (L)	22.42	30.34	26.293	1.662	0.143	20.52	28.31	23.818	1.671	0.153
11. HAF (L)	23.20	35.88	30.521	2.324	0.199	22.64	34.15	27.791	2.100	0.192
12.MAFB (L)	15.99	25.12	21.045	1.808	0.155	12.96	22.60	18.551	1.868	0.171

Min, minimum; Max, maximum; SD, Standard deviation, SE= The standard error of the mean

Table IV. Stepwise discriminant functions analyses.

Function 1	Variables	Classification Function Coefficients		Correctly classified	Average accuracy
		male	female	(%)	(%)
Function 1	MAXH (L)	2.154	1.848	83.2 %	82.8 %
	LAFB (L)	5.897	5.407		
	HLAF (L)	2.933	2.753		
	MAFB (L)	3.420	2.944		
	(Constant)	-203.520	-164.589		
Function 2	MAXH (R)	2.259	2.029	85.5 %	85.2 %
	MAXB (R)	2.402	2.183		
	LAFB (R)	5.723	5.218		
	MAFB (R)	2.824	2.455		
	(Constant)	-206.336	-167.957		

Example discriminant functions 2:Y male = 2.259 MAXH (R) +2.402 MAXB (R) +5.723 LAFB (R) +2.824 MAFB (R) -206.336. Y female = 2.029 MAXH (R) +2.183 MAXB (R) +5.218 LAFB (R) +2.455 MAFB (R) -167.957nts. The result with the greater value would be allocated to that sex. The percentage that was correctly classified using these equations was 85.5% (85.3% male, 85.8% female).

Table V. Direct discriminant functions analyses.

Function 1	**Variables**	**Classification Function Coefficients male**	**female**	**correctly classified (%)**	**Average accuracy (%)**
Function 1	MAXH (L)	1.153	0.884	84.0%	83.6%
	MAXB (L)	1.331	1.261		
	MAXT (L)	2.943	2.871		
	LAFB (L)	4.618	4.179		
	HLAF (L)	3.018	2.836		
	MAFB (L)	2.388	1.952		
	(Constant)	-216.523	-176.678		
Function 2	MAXH (R)	1.409	1.216	84.8%	84.8%
	MAXB (R)	1.636	1.451		
	MAXT (R)	3.518	3.366		
	LAFB (R)	4.899	4.429		
	HLAF (R)	2.362	2.261		
	MAFB (R)	2.093	1.755		
	(Constant)	-225.779	-185.881		

found 4 available measurements: MAXH (L), LAFB (L), HLAF (L), and MAFB (L) were selected. The percentage that was correctly classified using this equation was 83.2 % (83.8 % male, 82.5 % female). Function 2 found 4 available measurements: MAXH (R), MAXB (R), LAFB (R), and MAFB (R). The highest percentage that was correctly classified using these equations was 85.5 % (85.3 % male, 85.8 % female).

Table V shows the direct discriminant function analyses. A combination of all variables (left patella; function 1) showed an average accuracy of 83.6 %. The percentage that was correctly classified using these equations was 84.0 % (84.6 % male, 83.3 % female). On direct analysis using all variables, function 2 (right patella) showed an average accuracy of 84.8 %. The percentage that was correctly classified using these equations was 84.8 % (85.3 % male, 84.2 % female).

DISCUSSION

Sex determination is an important step that presents major challenges for skeletal identification in forensic cases (Austin & King, 2016). In many cases, only fragments of the pelvis and the skull are available, or these bones may be absent; therefore, an alternative approach based on other parts of the human skeleton, such as the patella is needed. The patella is a sesamoid bone that is normally found embedded within a tendon or muscle near joint surfaces. As the patella is well known as being the largest sesamoid bone in the knee joint (Yeung *et al*., 2023), sex determination based on a sesamoid bone in the body is recommended. The patella, which is located within the tendon of the quadriceps muscle, is particularly recommended because it is extremely resistant to postmortem and taphonomic changes (Jana *et al*., 2013). The average accuracy rate of more than 80 % in classifications using measurements of the patella for sex determination is higher than the accuracy rate for sex determination based on other bones in the Thai population, such as the mastoid process of the temporal bone (Sujarittham *et al*., 2011), and the zygomatic angle (Rattanasalee *et al*., 2014).

Although sex determination using patellar measurements is widely used for sex estimation in many populations (Introna Jr. *et al*., 1998; Peckmann *et al*. 2016; Peckmann & Fisher, 2018). There are differences in the lower limb sizes of populations due to environmental factors, genetic factors, or the interaction of both (Prior *et al*., 2007). It is therefore important to develop population-specific discriminant function equations to classify sex. This study used the patella, which can be applied to the estimation of sex in the Thai population. The measurements were selected and modified based on a study by Bidmos *et al*. (2005).

The results of the correlation analysis of the average intra-observer and inter-observer error rates were within range for all the variables, thus showing ICC consistency; a result > 0.85 was deemed acceptable. The results for the inter-observer errors ranged between 0.89 and 0.94, thus indicating high reliability among the individual measurements. This indicates minimal to negligible inter-observer error.

Table VI shows a comparison of the means of all the measurements of the patella bone in other populations. In the present study, the male mean values for each variable were greater than the female mean values. This is similar to previous studies, which also revealed that the male mean values were usually greater than those of females. Consequently, periosteal growth is inhibited by estrogen at puberty in females; thereafter, cortical thickness only changes because of apposition of endocortical bone. Therefore, it may be that women, who have naturally smaller skeletons, may also incur greater microarchitectural damage than men (Prior *et al*., 2007). According to Table VI, the MAXH for males and females showed that the bone lengths in this Thai population were less than those in Spanish (Peckmann *et al*., 2016), and African American populations (Peckmann & Fisher, 2018); apart from this, the values for the other variables were similar to those in other studies.

Srinak & Sukvitchai (2023) recently studied sex estimation from the patella in a Central Thai population. They used 130 samples (65 male and 65 female) and measured 6 variables, similar to this study. In that study, the stepwise discriminant function equations showed overall accuracy rates of 90 % for the left side and 93.3 % for the right side. The findings illustrated that the discriminant equation developed from the Northern Thai population could not be used for the central Thai population due to subpopulation variation. In the present study, the sample of 254 (134 men and 120 women) was derived from the Northern Thai population. The overall accuracy rates were 83.2 % for the left side and 85.5 % for the right side. These different accuracy rates may be due to different study sample sizes and subpopulation variation. The sex discriminant functions in our study apply to the patellae of Thai skeletons, particularly in the Northern Thailand region.

The results of this study were compared to those of previous studies of patellae in Thai populations, reported that the most useful variable for sex differentiation was LAFB, similar to Srinak & Sukvitchai (2023). In

Table VI. Comparison of mean values of patella bone variables with other population.

Authors Population	Population (year)	N	MAXH (mm)		MAXB (mm)		MAXT (mm)		LAFB (mm)		HAF (mm)		MAFB (mm)	
			Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Present study	Thai	254	41.37	36.76	44.16	39.95	20.86	19.01	26.29	23.81	30.52	27.79	21.05	18.55
Introna *et al*.,	Southern Italians (1998)	80	41.2	37	43.2	39.4	20.4	18.3	22.4	20.5	12.2	10.6	16.2	14.6
Bidmos *et al*.,	White South African (2005)	120	43.62	38.68	45.30	40.33	20.38	18.37	28.08	24.95	30.77	27.58	20.53	18.21
Dayal and Bidmos	Blacks South African (2005)	120	41.22	36.48	43.34	38.97	20.56	18.2	23.31	22.91	29.56	27.86	18.38	16.34
Phoophalee *et al*.,	Northern Thai (2012)	191	42.5	37	44.6	39.6	20.9	18.6	26.6*	23.6	30.6	28.2	20.6	18.2
Peckmann TR *et al*.,	Spanish (2017)	106	42.90	37.89	44.62	40.30	20.34	18.13	24.83	22.47	25.73	23.62	19.19	17.02
Peckmann TR *et al*.,	African American (2018)	200	44	39.75	45.01	39.79	20.8	19.16	24.38	21.51	32.86	29.58	20.81	18.01
Srinak *et al*.,	Central Thai(2023)	130	42.24	36.91	44.65	39.06	21.17	18.88	25.71	22.21	31.06	27.77	21.17	18.04

the present study, the most sexually dimorphic individual variables with the best accuracy were MAXH and MAXB. Several studies have concluded the same 2 variables as this study (Dayal & Bidmos, 2005; Bidmos *et al*., 2005). Other variables, MAXB and MAXT, were found by Introna Jr. *et al*. (1998) whereas Peckmann & Fisher (2018) found MAXH and MAXT.

Some factors must be considered when taking patellar measurements, particularly regarding morphological and biochemical changes in the articular cartilage due to age-related pathologic processes, such as osteoarthritis in the knee joint. This is most commonly seen in the elderly. The presence of bone spurs, also called osteophytes, could also affect the size of the patella (Nieves *et al*., 2005).

The accuracy rates obtained from the sex determination equations were more than 80 % for both direct and stepwise methods. This study provides sex estimation functions for various measurements that can be applied to the patella in Northern Thai individuals with accuracies of 85.5 % and 83.2 % for the right and left sides, respectively. However, the results also show that the accuracy of sex estimation using the patella is different in different populations.

CONCLUSION

The results of this study show the potential for sex estimation from patella bones in the northern Thai population when the skull and pelvis are absent. The metric method of sex estimation using the patella can be used to identify sex with great accuracy, especially in the Northern Thai population.

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CHOMPOOPHUEN, H.; TIPMALA, J.; DUANGTO, P & MAHAKKNUKRAUH, P. Determinación del sexo a partir de la rótula en una población tailandesa. *Int. J. Morphol., 42(4)*:891-897, 2024.

RESUMEN: El objetivo de este estudio fue derivar las ecuaciones para la determinación del sexo y probar la precisión de la discriminación entre sexos utilizando mediciones de la patela en la población tailandesa. La muestra estuvo compuesta por 254 esqueletos tailandeses (134 hombres y 120 mujeres) con edades comprendidas entre 22 y 97 años, con una edad promedio de 63,3 años, del Centro de Investigación y Capacitación en Osteología de la Facultad de Medicina de la Universidad de Chiang Mai, Chiang Mai. Se midieron seis variables en 254 pares de patelas normales. Los valores medios de las mediciones patelares en los hombres fueron significativamente mayores que los de las mujeres, para todas las variables (P <0,05). Además, el análisis estadístico mostró que todas las variables fueron útiles para la determinación del sexo. El análisis de la función discriminante por pasos arrojó una precisión del 83,2 % (83,8 % hombres, 82,5 % mujeres) y 85,5 % (85,3 % hombres, 85,8 % mujeres) para las patelas izquierda y derecha, respectivamente. Estos resultados sugieren que la medición de la patela derecha es preferible para la determinación del sexo en esqueletos. En caso de no estar disponible y para dar una clasificación correcta, el especialista forense puede utilizar la patela izquierda, con una precisión promedio de más del 80,0 %. Los hallazgos de este estudio demuestran que la patela es un hueso importante en la determinación del sexo. Se sugiere que se pueda utilizar la patela izquierda o derecha para determinar el sexo, especialmente en la población del norte de Tailandia.

PALABRAS CLAVE: Antropología forense; Determinación del sexo; Patela; Población tailandesa.

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