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A Comparison of Effectiveness of Sex Estimation from the Calcaneus and Talus in a Thai Population

Comparación de la Efectividad de la Estimación del Sexo a Partir del Calcáneo y el Talus en una Población Tailandesa

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SUMMARY: Sex estimation is an important aspect of skeletal identification. In addition, previous studies have found that the sex estimation of each race is different. Thus, it is necessary to develop discriminant function equations for the estimation of sex for the Thai population. This study aims to investigate the relationship between width, length and height of the calcaneus and talus with regards to sex and compare the effectiveness of sex estimation between the calcaneus alone, the talus alone, and between both the calcaneus and talus. A total of 200 individuals (100 males and 100 females) were used in this study; ages ranged from 19 to 94 years. Thirteen variables of calcaneus and ten variables of talus were measured. The authors created discriminant function equations for the estimation of sex and tested the efficiency of the equations obtained by using a test group of 40 individuals (20 males and 20 females). By analyzing the mean values of the variables in the calcaneus and the talus, it was shown that males were significantly different from females ($p<0.05$). Except for the Minimum Inferior Interarticular Distance (MinIID) variable in the left and right talus, the mean of the male and female variables was not significantly different ($p>0.05$). A stepwise method was used to create 6 equations for sex estimation. The equations were categorized from between the calcaneus alone, the talus alone, and between both the calcaneus and the talus, providing a sex estimation accuracy of between 88.5 and 93.0 %. Using the test group, it was shown that discriminant function equations from the calcaneus alone, the talus alone, and the calcaneus and the talus together, can estimate sex at a high level of accuracy. Sex estimation accuracy was greater than 85 % in all equations. Therefore, the discriminant function equations from the calcaneus alone, the talus alone, and between both the calcaneus and the talus, from this study can be applied to the Thai population.

KEY WORDS: Sex estimation; Calcaneus; Talus; Thailand.

INTRODUCTION

Nowadays, crimes are found frequently, with crimes causing serious problems for society, including crimes against property, crimes against life and body, sex crimes, and crimes involving impersonation of personal information. This includes murder cases involving the killing, dismemberment, or dismemberment of a body to disguise the case by causing the condition of the corpse to be damaged or leave only the skeleton. Disasters are a cause that affects and damages people's lives and properties, as well. In 2004, Thailand experienced a tsunami, causing the deaths and missing persons of more than 5,395 people. Anonymous bodies have also been found that cannot be identified. Therefore, skeletal identification is very useful in forensic procedures. It can be used to identify ancestry, sex, age and stature (Mann & Ubelaker, 1990).

Sex estimation from unknown skeletons is a very important step in biological identification (Traithepchanapai *et al*., 2016). The age estimation and height estimation process relies on sex estimation data. Sex estimation can increase the likelihood of identification by 50 %. The process of estimating the sex from a skeleton is divided into two

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methods: Morphological methods, using observation of anatomy (the morphological method) of the pelvis and skull, and bone measurements (the osteometric method). Bone measurements can also be used in conjunction with identification (Phenice, 1969). Morphological methods are easier and faster than other methods of sex estimation (Krogman, 1939). However, morphological methods are observation-based methods and require a person with considerable orthopedic experience. Therefore, in order to reduce the limitations of such methods, bone measurement methods can be used which are free from individual interpretation and exhibit a degree of accuracy as used in this study (MacLaughlin & Bruce, 1990). In addition, there are some cases where the pelvis and skull bones cannot be found at the scene. Therefore, there are people who are interested in using other bones to study sex estimation, such as upper extremities (Duangto & Mahakkanukrauh, 2020), including the sternum (Mahakkanukrauh, 2001), scapula (Peckmann *et al*., 2017) and metacarpals (Khanpetch *et al*., 2012). The calcaneus and talus are two other interesting bones, because they are bones that are dense and strong, difficult to be destroyed and subject to deterioration (Weaver *et al*., 2016).

From previous studies of sex estimation on the calcaneus and talus, studies have been conducted in other ethnic groups, such as Indians (Sumati & Phatak, 2017), Northern Italians (Gualdi-Russo, 2007) and Japanese (Sakaue, 2011), and have shown that the calcaneus and talus can be used to estimate the sexes. Each population has differences in genetics, environment and lifestyle. As a result, the width, length and height of the bones exhibit differences (Frutos, 2005). Therefore, the authors had an idea to develop discriminant function equations for the estimation of sex for the Thai population. However, it would be very helpful to be able to perform estimation of sex from the calcaneus and talus in the initial examination, without the need of probing technology for bone measurements. For this reason, the researcher is interested in a comparison of effectiveness of sex estimation from the calcaneus and talus in the Thai population.

MATERIAL AND METHOD

This protocol is exempt from review by the Research Ethics Committee of Faculty of Medicine, Chiang Mai University (study code: ANA-2564-08698)

Sample Group. The present study examined the calcaneus and talus of 240 individuals from the Osteology Research and Training Center (ORTC) in the Faculty of Medicine at Chiang Mai University, by knowing the sex of the sample

Table I Measurement descriptions of the calcaneus. (Sumati *et al*., 2017 and Wanpradab *et al*., 2011).

Measurement	Description
Maximum length (MaxL)	Maximum linear distance between the most anterior point of the cuboidal facet and the most posterior point of the calcaneal tuberosity.
Minimum width (MinW)	Minimum linear distance between the lateral and medial of the calcaneus body.
Body height (BH)	Linear distance between the superior and inferior of the calcaneus body; between the most posterior point of posterior articular facet and the most anterior point of the calcaneal tuberosity.
Load arm length (LAL)	Maximum linear distance between the most anterior point of the articular surface for cuboid and the most posterior point of the posterior articular facet.
Load arm width (LAW)	Maximum linear distance between the most lateral point of the posteriorarticular facet and the most medial point of the sustentaculum tali.
Anterior articular facet length (AAFL)	Maximum linear distance between the most anterior point and the most posterior point of the anterior articular facet.
Anterior articular facet width (AAFW)	Maximum linear distance between the most medial point and the most lateral point of the anterior articular facet.
Middle articular facet length (MAFL)	Maximum linear distance between the most anterior point and the most posterior point of the middle articular facet.
Middle articular facet width (MAFW)	Maximum linear distance between the most medial point and the most lateral point of the middle articular facet.
Dorsal articular facet length (DAFL)	Maximum linear distance between the most anterior point and the most posterior point of the posterior articular facet.
Dorsal articular facet width (DAFW)	Maximum linear distance between the most medial point and the most lateral point of the posterior articular facet.
Cuboidal facet height (CFH)	Maximum linear distance between the most superior point and the most inferior point of the cuboidal facet.
Cuboidal facet width (CFW)	Maximum linear distance between the most medial point and the most lateral point of the cuboidal facet.

used in the study. They were divided into two groups: Firstly, 200 individuals were used for constructing the training group (100 males and 100 females). The collection represents the Thai nationality and ages ranged from 19 to 94 years with an average age of 63.18 ± 14.73 years (males 64.25 ± 13.93 years, and females 62.11 ± 15.49 years). Secondly, 40 individuals were used for constructing the test group (20 males and 20 females). They were used to test the effectiveness of discriminant function equations without information on the sex of the skeleton. The skeleton must have had a clear landmark and facet, and been free from disease or pathological abnormalities of the bone and damage, such as bone spur, osteoporosis, osteoarthritis or broken bone.

Data Collection. Thirteen variables of the calcaneus and ten variables of the talus were measured with a digital vernier caliper, data were recorded using millimeter measurements and repeated three times of each variable. The mean of each variable was recorded for each individual.

A description of the parameters of the calcaneus and talus measurements are shown in Tables I and II. The measurement for each variable is shown in Figures 1 and 2.

Data Analysis. This study tested the reliability of measurements used in 20 individuals for examining the relationship between inter-observers using paired sample T-Test statistics. In addition, descriptive statistics were used to find the minimum, maximum, mean and standard deviation to describe the measurement value of each variable. For an analysis of the distribution of data from the sample, the researchers used a Kolmogorov-Smirnov Test and paired sample T-Test statistics to compare the differences in width, length and thickness of the calcaneus and talus between the left side and right side.

For creating discriminant function equations for a Thai population, we used statistical analysis to classify groups (Discriminant analysis) using a stepwise method to construct discriminant function equations from the left side and right side of the calcaneus, the talus, and then both calcaneus and talus. The efficacy of discriminant function equations was also tested using a test group of 40 individuals (20 males and 20 females).

The data were analyzed using the statistical analysis program SPSS (Statistical Package for the Social Sciences), with the significance level set at 0.05.

RESULTS

The results of the reliability test of Inter-observer measurements of 20 calcaneus and talus (10 males and 10 females) were found to have a correlation coefficient (r) ranging from 0.878 to 1.000, showing that the reliability between the 1st and 2nd measurers was consistent ($p<0.05$) (Table III).

From the analysis of calcaneus and talus measurement data with descriptive statistics, it was found that the mean of all variables in calcaneus and talus measurements of the

Table II Measurement descriptions of the talus. (Mahakkanukrauh *et al*., 2014).

Measurement	Description
Maximum talar length (MaxTL)	Maximum linear distance between the most anterior point of the talus head and the most posterior of the trigonal process.
Maximum talar width (MaxTW)	Maximum linear distance between the most lateral malleolar articular surface point and the most medial surface point of talus.
Maximum talar height (MaxTH)	Maximum linear distance between the most superior of the lateral malleolar articular surface point and the most inferior of talus.
Maximum trochlear length (MaxTrL)	Maximum linear distance between the most anterior point and the most posterior point of the trochlear.
Maximum trochlear width (MaxTrW)	Maximum linear distance between the most medial point and the most lateral point of the trochlear.
Maximum length of the inferior articular surface (MaxLIAS)	Maximum linear distance between the most medial point and the most lateral point of the posterior subtalar facet.
Maximum width of the inferior articular surface (MaxWIAS)	Maximum linear distance between the most anterior point and the most posterior point of the posterior subtalar facet.
Minimum inferior interarticular distance (MinIID)	Minimum linear distance between the most anterior point of the posterior subtalar facet and the most posterior point of the medial subtalar facet.
Maximum lateral malleolar surface height (MaxLMSH)	Maximum linear distance between the most superior point and the most inferior point of the lateral malleolar articular surface.
Minimum interarticular distance across the neck (MinIDAN)	Minimum linear distance between the edge of the medial malleolar articular surface and the edge of the articular surface of the talus head.

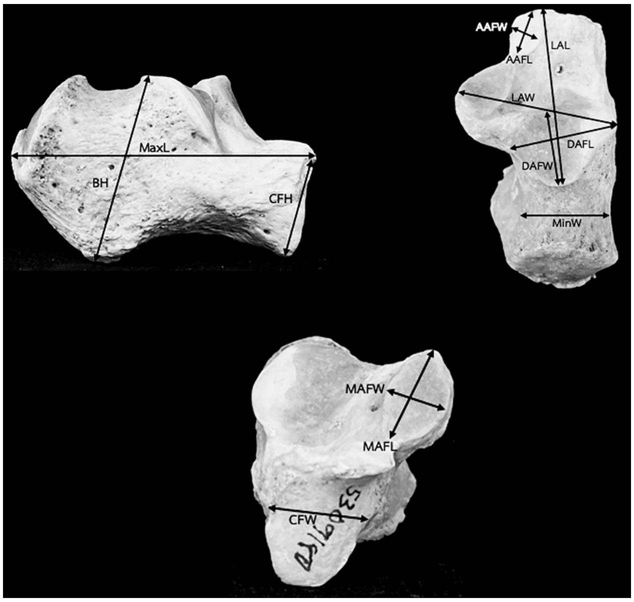

Fig. 1. Measurement of the calcaneus: lateral view, dorsal view, anterior view; Maximum length (MaxL), Body height (BH), Cuboidal facet height (CFH), Minimum width (MinW), Load arm length (LAL), Load arm width (LAW), Anterior articular facet length (AAFL), Anterior articular facet width (AAFW), Dorsal articular facet length (DAFL), Dorsal articular facet width (DAFW), Middle articular facet length (MAFL), Middle articular facet width (MAFW), and Cuboidal facet width (CFW).

males was significantly more than the females ($p<0.05$). Except for the Minimum Inferior Interarticular Distance (MinIID) variable in the left and right talus, the mean between males and females was not significantly different ($p>0.05$) (Tables IV and V). From the study data, it was shown that discriminant function equations using the calcaneus and talus should be created into discriminant function equations for the left and right sides.

Six equations were used to create a stepwise method of discriminant function equations, divided into discriminant function equations for left and right calcaneus alone, discriminant function equations for left and right talus alone, and discriminant function equations for both calcaneus and talus with the left and right sides. Each discriminant function equation contains identical and different variables. Discriminant function equations for the calcaneus consist of 6 and 4 variables for the left and right, respectively. Discriminant function equations for the talus consist of 6 variables for the left and 3 for the right. And discriminant function equations for the calcaneus and the talus consist of 8 variables for the left side (7 variables from the talus) and 7 variables for the right side (6 variables from the talus). In addition, when discriminant function equations were used to test the efficiency of the stepwise method, it was shown that discriminant function equations were more than 85 % accurate in all equations (Table VI). For the accuracy of discriminant function equations that tested the efficiency of the equations obtained using a test group of 40 individuals, it was shown that the left calcaneus and both the left and right talus had the highest sex estimating accuracy, at 90 %, both the left and right calcaneus and the talus together had sex estimating accuracy of 88 %, and the right calcaneus had sex estimating accuracy of 86 %, as shown in Table VII.

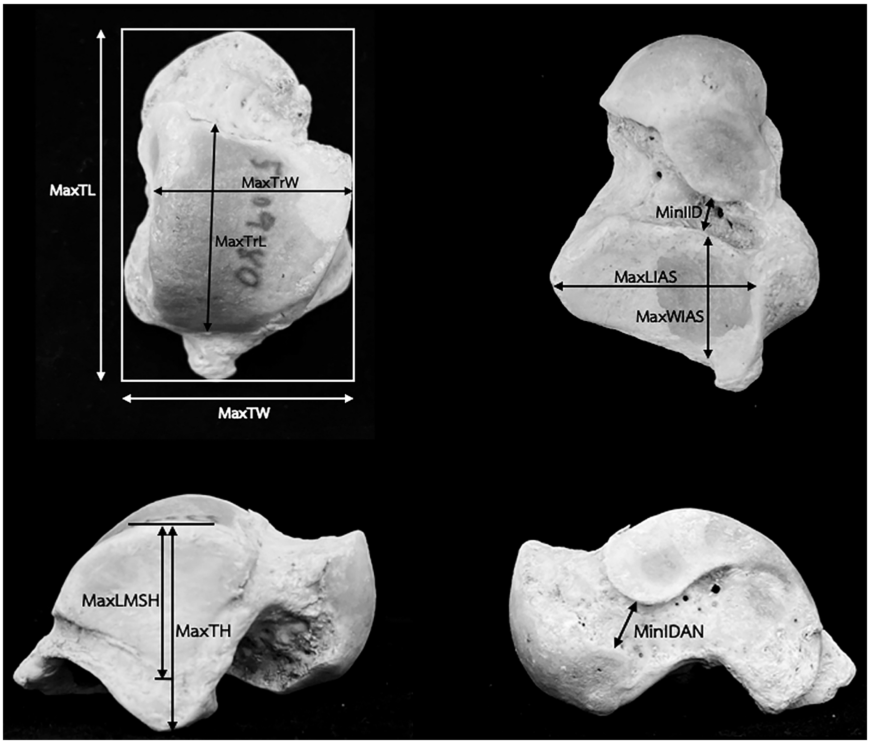

Fig. 2. Measurement of the talus: dorsal view, plantar view, lateral view, medial view. Maximum talar length (MaxTL), Maximum talar width (MaxTW), Maximum trochlear length (MaxTrL), Maximum trochlear width (MaxTrW), Maximum length of the inferior articular surface (MaxLIAS), Maximum width of the inferior articular surface (MaxWIAS), Minimum inferior interarticular distance (MinIID), Maximum lateral malleolar surface height (MaxLMSH), Maximum talar height (MaxTH), and Minimum interarticular distance across the neck (MinIDAN).

Table III Correlation coefficient for Inter-observer reliability.

Measurement	Left			Right		
	N	Correlation	*p*-value	N	Correlation	*p*-value
Calcaneus						
MaxL	20	0.997	0.000	20	0.997	0.000
MinW	20	0.999	0.000	20	1.000	0.000
BH	20	0.999	0.000	20	1.000	0.000
LAL	20	0.998	0.000	20	0.999	0.000
LAW	20	0.999	0.000	20	0.999	0.000
AAFL	20	0.998	0.000	20	0.987	0.000
AAFW	20	0.996	0.000	20	0.998	0.000
MAFL	20	0.999	0.000	20	0.999	0.000
MAFW	20	0.878	0.000	20	0.997	0.000
DAFL	20	0.995	0.000	20	0.999	0.000
DAFW	20	0.998	0.000	20	0.998	0.000
CFH	20	0.999	0.000	20	0.999	0.000
CFW	20	0.999	0.000	20	0.971	0.000
Talus						
MaxTL	20	1.000	0.000	20	1.000	0.000
MaxTW	20	1.000	0.000	20	0.999	0.000
MaxTH	20	0.999	0.000	20	0.998	0.000
MaxTrL	20	1.000	0.000	20	0.993	0.001
MaxTrW	20	0.999	0.000	20	0.999	0.000
MaxLIAS	20	1.000	0.000	20	0.999	0.000
MaxWIAS	20	0.993	0.000	20	0.999	0.000
MinIID	20	0.999	0.000	20	0.995	0.000
MaxLMSH	20	0.999	0.000	20	0.996	0.000
MinIDAN	20	0.998	0.000	20	0.999	0.000

Table IV Descriptive statistics for calcaneus.

Measurement (mm)	Males (n=100)			Females (n=100)			*t*-value	*p*-value
	Min-Max	Mean	SD	Min-Max	Mean	SD		
L-MaxL	71.08-91.21	80.69	4.20	64.35-84.13	73.28	3.99	12.779	< 0.05
R-MaxL	71.80-90.80	80.62	4.13	63.68-84.44	73.31	4.00	12.722	< 0.05
L-MinW	21.70-30.61	26.17	2.10	19.00-28.14	23.27	1.60	10.987	< 0.05
R- MinW	21.57-31.26	26.11	1.98	19.39-27.54	23.28	1.69	10.873	< 0.05
L-BH	31.61-45.53	40.34	2.28	31.44-42.77	36.35	2.37	12.108	< 0.05
R-BH	32.33-46.21	40.79	2.38	31.31-42.40	36.79	2.30	12.077	< 0.05
L-LAL	37.04-52.47	43.58	2.55	30.69-46.84	39.52	2.57	11.210	< 0.05
R-LAL	37.36-53.54	43.71	2.74	32.05-48.47	39.60	2.87	10.343	< 0.05
L-LAW	34.65-45.24	40.41	2.17	30.47-41.16	36.23	1.86	14.595	< 0.05
R- LAW	33.71-44.18	40.06	2.10	30.48-41.80	36.03	2.00	13.873	< 0.05
L-AAFL	6.55-16.01	11.73	1.89	7.63-14.04	11.20	1.39	2.258	< 0.05
R-AAFL	6.50-15.91	11.95	1.99	7.71-14.79	10.99	1.37	3.851	< 0.05
L-AAFW	5.26-12.37	8.56	1.51	5.06-10.79	7.83	1.26	3.733	< 0.05
R-AAFW	4.95-12.94	8.58	1.59	4.09-10.92	7.79	1.29	3.851	< 0.05
L-MAFL	14.13-24.34	20.19	1.80	13.01-22.96	17.74	1.81	9.600	< 0.05
R-MAFL	14.51-24.41	20.06	2.08	13.00-22.78	18.20	1.96	6.872	< 0.05
L-MAFW	8.99-14.26	11.65	0.97	7.81-13.01	10.53	1.07	7.744	< 0.05
R-MAFW	9.18-14.45	11.72	1.02	8.09-13.65	10.57	1.14	7.460	< 0.05
L-DAFL	23.11-32.37	28.51	1.86	19.95-27.92	25.04	1.58	14.240	< 0.05
R-DAFL	23.46-32.09	28.52	1.85	20.31-29.06	25.20	1.52	13.843	< 0.05
L-DAFW	16.72-23.99	20.17	1.54	15.25-20.52	17.94	1.23	11.314	< 0.05
R-DAFW	17.13-24.71	20.23	1.51	15.21-21.30	18.04	1.31	10.942	< 0.05
L-CFH	20.39-28.92	24.55	1.80	17.32-24.88	21.63	1.47	12.543	< 0.05
R-CFH	21.54-29.86	25.24	1.78	17.09-25.85	21.98	1.54	13.833	< 0.05
L-CFW	18.23-25.41	21.59	1.47	15.23-23.23	19.40	1.70	9.698	< 0.05
R-CFW	18.31-25.16	21.43	1.61	14.36-24.05	19.24	1.63	9.555	< 0.05

Table V Descriptive statistics for talus.

Measurement (mm)	Males (n=100)			Females (n=100)			*t*-value	*p*-value
	Min-Max	Mean	SD	Min-Max	Mean	SD		
L-MaxTL	49.28-64.54	55.94	2.77	42.19-56.02	49.94	2.70	15.443	< 0.05
R-MaxTL	49.11-64.92	56.36	2.85	43.20-57.06	50.57	2.64	14.849	< 0.05
L-MaxTW	36.01-46.01	41.29	2.13	31.63-41.43	37.42	1.85	13.752	< 0.05
R-MaxTW	36.31-47.05	41.24	2.21	31.73-42.46	37.44	1.99	12.783	< 0.05
L-MaxTH	25.17-33.49	29.26	1.80	22.41-30.52	26.57	1.51	11.424	< 0.05
R-MaxTH	23.91-33.82	28.99	1.93	21.67-31.43	26.35	1.64	10.430	< 0.05
L-MaxTrL	28.20-39.05	34.00	1.90	26.44-34.69	30.16	1.89	14.482	< 0.05
R-MaxTrL	27.20-38.69	33.40	2.05	25.22-35.13	29.63	1.95	13.602	< 0.05
L-MaxTrW	24.41-31.63	27.52	1.60	19.31-28.75	24.55	1.63	12.975	< 0.05
R-MaxTrW	24.46-32.15	27.86	1.55	20.94-28.49	24.89	1.57	13.419	< 0.05
L-MaxLIAS	26.54-34.78	30.76	1.59	22.09-30.36	27.09	1.59	16.312	< 0.05
R-MaxLIAS	26.67-34.26	30.87	1.57	22.33-31.26	27.21	1.60	16.274	< 0.05
L-MaxWIAS	17.55-24.08	20.73	1.27	16.09-21.19	18.25	1.21	14.164	< 0.05
R-MaxWIAS	17.84-23.95	20.69	1.22	15.73-21.42	18.46	1.19	13.098	< 0.05
L-MinIID	3.16-8.11	5.21	0.95	2.70-8.20	5.17	1.06	0.263	0.793
R-MinIID	3.15-8.18	5.25	0.94	2.85-7.73	5.03	1.07	1.613	0.108
L-MaxLMSH	18.59-27.00	22.66	1.92	18.52-25.52	21.52	1.50	4.626	< 0.05
R-MaxLMSH	17.58-27.76	22.40	2.06	17.33-24.54	21.32	1.60	4.178	< 0.05
L-MinIDAN	3.88-11.52	7.12	1.64	3.36-11.83	6.40	1.57	0.354	< 0.05
R-MinIDAN	3.57-11.93	7.05	1.70	3.30-10.56	6.38	1.56	0.430	< 0.05

DISCUSSION

Current weather conditions in Thailand such as summer storms, rising sea levels and flooding, are indicative of an increasing frequency and severity of such incidents in the future. It could also be the cause of severe disasters and increased death tolls (Marks, 2011). Therefore, as the number of unknown skeletons increases as a result of this loss, identification of the deceased requires skeletal identification data that includes sex, age, stature and ancestry (Mann & Ubelaker, 1990). Sex estimation is a very important step. This is because sex data can limit the probability size of the data to being approximately 50 % smaller (El Najjar & McWilliams, 1978; Krogman & Is¸can, 1986).

Sex estimation from skeletons has found that the pelvic bone and skull have the highest sex estimation accuracy (Phenice, 1969; Ferembach *et al*., 1980; Mahakkanukrauh *et al*., 2017). However, although these two bones are often found at the crime scene, they are often fragmented, making them unable to be used for sex estimation (Kim *et al*., 2010; Peckmann *et al*., 2015). Therefore, sex estimation requires another bone. The calcaneus and the talus are often found at the crime scene because both bones have a dense structure and a thick layer of bone, and are thus protected from destruction by shoes (Bidmos & Asala, 2003; Tuller, 2006). Therefore, the calcaneus and the talus are interesting bones for sex estimation. In previous studies, both bones were able to be used for sex estimation and exhibited a high level of reliability (Table VIII) (Sumati & Phatak, 2017; Sakaue, 2011; Wanpradab *et al*., 2011; Mahakkanukrauh *et al*., 2014).

From the measurements of width, length and height of the calcaneus and the talus, it has been shown that the mean values of all variables are significantly higher in males than females (Tables IV and V). This is consistent with previous studies on sex estimation from the calcaneus and the talus (Bidmos & Asala, 2003, 2004; Gualdi-Russo, 2007; Kim *et al*., 2013; Mahakkanukrauh *et al*., 2014; Peckmann *et al*., 2015). It has consistently been shown that males have larger bone sizes and body proportions than females due to biological differences (El Najjar & McWilliams, 1978).

Regarding discriminant function equations for the Thai population from the calcaneus alone, the talus alone, and between the calcaneus and talus together using a stepwise method, it was shown that each equation consists of both the same and different variables. Therefore, each equation has a different ability to correctly determine the estimation of sex. When considering discriminant function equations for the calcaneus, it was shown that all variables could be used to create the discriminant function equations. However, when using a stepwise method, it was shown that only 4 variables were needed to form the discriminant function equations. The most effective variable was the Dorsal Arti-

Table VI Correct classification of discriminant function equations from the calcaneus alone, the talus alone and the calcaneus and the talus by stepwise method.

Measurements	Unstandardized coefficient	Standardized coefficient	Structure matrix	Centroids	Sectioning point	Averag accurac
Calcaneus						
(Left)						91.5 %
LAW	0.110	0.222	0.769	M= 1.342	0	
MAFL	0.155	0.281	0.506	F= -1.342		
DAFL	0.203	0.350	0.750			
DAFW	0.163	0.228	0.596			
CFH	0.168	0.276	0.661			
CFW	0.130	0.208	0.511			
Constant	-22.245					
(Right)						88.5 %
LAW	0.133	0.273	0.771	M= 1.272	0	
DAFL	0.212	0.360	0.770	F= -1.272		
DAFW	0.196	0.277	0.608			
CFH	0.268	0.447	0.769			
Constant	-20.831					
Talus						
(Left)						92.5 %
MaxTL	0.126	0.345	0.749	M= 1.454	0	
MaxTH	0.242	0.402	0.556	F= -1.454		
MaxTrL	0.169	0.319	0.697			
MaxLIAS	0.318	0.505	0.793			
MinIID	-0.192	-0.193	0.013			
MaxLMS	-0.258	-0.445	0.229			
Constant	-21.288					
(Right)						92.0 %
MaxTrL	0.185	0.369	0.711	M= 1.328	0	
MaxTrW	0.220	0.344	0.715	F= -1.328		
MaxLIAS	0.357	0.567	0.867			
Constant	-22.003					
Calcaneus & Talus						93.0 %
(Left)						
MAFL	0.142	0.256	0.446	M= 1.521	0	
CFH	0.124	0.204	0.583	F= -1.521		
MaxTL	0.100	0.275	0.716			
MaxTH	0.218	0.363	0.531			
MaxTrL	0.125	0.237	0.667			
MaxLIAS	0.263	0.419	0.759			
MinIID	-0.222	-0.223	0.012			
MaxLMSH	-0.256	-0.441	0.219			
Constant	-21.803					
(Right)						91.5 %
CFH	0.219	0.364	0.657	M= 1.489	0	
MaxTW	-0.142	-0.298	0.607	F= -1.489		
MaxTH	0.240	0.430	0.495			
MaxTrL	0.153	0.306	0.634			
MaxTrW	0.208	0.325	0.637			
MaxLIAS	0.344	0.547	0.773			
MaxLMSH	-0.260	-0.479	0.198			
Constant	-20.841					

cular Facet Length (DAFL), or DAL, which was the variant found in the discriminant function equations for the calcaneus in this study that was most consistent with previous results (Sumati & Phatak, 2017; Wanpradab *et al*., 2011; Scott *et al*., 2017). As shown in Table VIII, the second influencing variables were the Load Arm Width (LAW), or MIDB and MAXB, which is consistent with the Sumati & Phatak (2017), and Scott *et al*. (2017) studies. In addition, the variable for Dorsal Articular Facet Width (DAFW), or DAW, was consistent with Wanpradab *et al*. (2011). When considering the correct classification for males and females, it was shown that females had correct classification more than males, which is consistent with previous studies (Bidmos & Asala, 2003, 2004; Peckmann *et al*., 2015; Scott *et al*., 2017). And when comparing the correct classification values, it was shown that this study had similarly correct classification values that were consistent with Sakaue (2011) and Scott *et al*. (2017). Therefore, when considering the variables of the equation, it was shown that the variables of the equation were related to the region of the articular surface, which was consistent with Dwight (1905) research. The differences in the size of the articular surfaces between sexes were more prominent than bone length in determining sex differences. Moreover, Wilbur (1998) showed that the discriminant function equation was most accurate in the estimation of sex when the calcaneus and articular facets were included as components of the equation. And when considering the study by Sumati & Phatak (2017), it was shown that the variables for the calcaneus discriminant function equations consisted of variables related to the articular surface and exhibited high correct classification values. Even if the posterior calcaneus is damaged, but by no more than 1/3 of the entire posterior calcaneus, the calcaneus can

Table VII Sex estimation accuracy of the calcaneus alone, the talus alone and the calcaneus and the talus by stepwise method by using a test group of 40 individuals.

Discriminant model	Sex estimating accuracy (%)
(1) Calcaneus (Left)	90.0
(2) Calcaneus (Right)	86.0
(3) Talus (Left)	90.0
(4) Talus (Right)	90.0
(5) Calcaneus & Talus (Left)	88.0
(6) Calcaneus & Talus (Right)	88.0

still be used in the estimation of sex.

For the discriminant function equations for a Thai population from the talus by separating left and right, it was shown that all variables could be used to construct all discriminant function equations, except for the left and right Minimum Inferior Interarticular Distance (MinIID). However, when using stepwise statistical analysis, it was shown that only 2 variables were needed to form the discriminant function equations. The most effective variable was MaxTrL, or MaxTrLg or TrL, which is consistent with Mahakkanukrauh *et al*. (2014), Bidmos & Dayal (2004), and Lee *et al*. (2012). Additionally, MaxLIAS, or LPAS, is consistent with Sakaue (2011) and Lee *et al*. (2012). Therefore, it can be seen that the variables related to the articular surface are the variables that have the greatest ability to differentiate between sexes. When comparing the correct classification values, it was shown that this study had correct classification values more often than Bidmos & Dayal (2004) and Lee *et al*. (2012), and values similar to other previous studies (Gualdi-Russo, 2007; Sakaue, 2011; Mahakkanukrauh *et al*., 2014). As shown in Table VIII, when comparing the same ethnic group, it was shown that the maximum trochlear length variable was still a good variable for estimating sex among the Thai population (Mahakkanukrauh *et al*., 2014). As for discriminant function equations for the Thai population from the calcaneus and the talus separated into left and right using a stepwise method, it was shown that all 5 variables were selected to form the discriminant function equations. The most effective variants were MaxTrL and MaxLIAS, which is consistent with Sakaue (2011). When considering discriminant function equations, it was shown that most of the variables of the equation were those from measurements of the articular surface of the talus, which is consistent with Sakaue (2011).

Regarding the accuracy of the discriminant function equations, it was shown that discriminant function equations from the calcaneus and the talus were more accurate than the discriminant function equations from the calcaneus alone, and the accuracy was similar to discriminant function equations from the talus alone, as shown in Table VII. Therefore, such knowledge can be applied in real situations at the crime scene. When both the calcaneus and the talus are found, they should both be used for estimating sex. However, if only one bone may be found, it was shown that the talus had the highest level of accuracy in sex estimation. This is consistent with Gualdi-Russo (2007) and Sakaue (2011).

Table VIII Comparison of the best variables of the calcaneus alone, the talus alone and the calcaneus and the talus with different populations.

Bone	Authors	Year	Population	Best sex determination	Correct Classification (%)
Calcaneus	Gualdi-Russo	2007	Northern Italian	Breadth & Length of calcaneus	91.0 (Left.), 88.5 (Right.)
	Sakaue	2011	Japanese	Total length of the calcaneus & Breadth of the tuber calcanei	89.0 (Left.), 87.0 (Right.)
	Wanpradab *et al.*	2011	Thai	ML, DAL & DAW	90.5 (Left), 91.0 (Right)
	Sumati & Phatak	2017	Indian	MAXB & DAFL	94.3
	Scott *et al.*	2017	Thai	BH, MIDB &DA FL	87.0
	Present study	2022	Thai	LAW, DAFL, DAFW & CFH	91.5 (Left), 88.5 (Right)
Talus	Bidmos & Dayal	2004	South African black	HH, TrB & TrL	89.2
	Gualdi-Russo	2007	Northern Italian	Length of talus	91.5 (Left), 90.7 (Right)
	Sakaue	2011	Japanese	Talar body height, Breath of the trochlea, Head-neck length & Length of the posterior articular surface	94.0 (Left.), 92.0 (Right.)
	Lee *et al.*	2012	Koreans	TL, TW, TH, TrL, TrB, HNL, HH, LPAS, BPAS	87.9
	Mahakkanukrauh *et al.*	2014	Thai	MaxTrLg & MaxTrBr	91.4 (Left) 91.3 (Right)
	Present study	2022	Thai	MaxTrL & MaxLIAS	92.5 (Left) 92.0 (Right)
Calcaneus & Talus	Gualdi-Russo	2007	Northern Italian	Length of calcaneus & talus	93.9 (Left) 92.2 (Right)
	Sakaue	2011	Japanese	Total length of the calcaneus, breadth across the sustentaculum, length of the trochlea, breadth of the trochlea, head neck length and length of the posterior articular surface	94.0 (Left) 92.0 (Right)
	Present study	2022	Thai	CFH, MaxTH, MaxTrL, MaxLIAS & MaxLMSH	93.0 (Left) 91.5 (Right)

This study presents discriminant function equations from the calcaneus alone, the talus alone, and the calcaneus and the talus together using a stepwise method. Skeletal identification is very useful in forensic science. This study used methods to measure the calcaneus and the talus. It is simple, cheap and rapid. The bones that are most commonly used for sex estimation are the pelvis and skull. However, if the pelvis and skull are not found, but only one calcaneus bone or talus bone is found, or both are found at the crime scene, the calcaneus and the talus are alternatives that can be used in the estimation of sex using bone measurement methods. The values of the variables can be substituted in the equations obtained from this study.

This study can be used to develop and extend future studies by increasing the size of the population. Alternatively, the discriminant function equations obtained in this study may be tested on samples of Thai populations in other regions. This study was a study of the Northern Thai population, and other methods have been used in further studies, such as three-dimensional imaging, imagery from other medical devices, neural network methods, or artificial intelligence, in order to develop techniques and methods of study that will be more effective and thereby increase the accuracy of sex estimation from the calcaneus alone, the talus alone, or the calcaneus and the talus together, for the benefit of more effective identification in forensic anthropology.

CONCLUSION

This study aims to investigate the relationship between width, length and height of the calcaneus and talus with sex, and to compare the effectiveness of sex estimation between the calcaneus alone, and talus alone, and between the calcaneus and talus, in a Thai population by constructing discriminant function equations. According to this study, the calcaneus and the talus can be used in the estimation of sex. Six equations for sex estimation were generated using a stepwise method. It was shown that sex estimation accuracy from the left and right calcaneus alone was 91.5 % and 88.5 %, respectively. For the left and right talus alone, it was 92.5 % and 92 %, respectively. For the left and right from the calcaneus and the talus, it was 93 % and 91.5 %, respectively. Therefore, these sex estimation accuracy values of between 85 % and 90 % are high. Compared to previous studies, sex estimation from the calcaneus and the talus provides high sex estimation accuracy and reliability. This study can be used to develop and extend future studies by increasing the size of the population. Alternatively, the discriminant function equations obtained in this study may be tested on samples of Thai populations in other regions. Increased study techniques and methods and increased accuracy of sex estimation from the calcaneus alone, the talus alone, and the calcaneus and the talus together, offer benefits for forensic science and forensic anthropology for more efficient skeletal identity verification.

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OUAMTHONG, R.; MAHACHAROEN, T.; INTHASAN, C.; SRISINGHASONGKRAM, J.; SINGSUWAN, P. & MAHAKKANUKRAUH, P. Comparación de la efectividad de la estimación del sexo a partir del calcáneo y el talus en una población tailandesa. *Int. J. Morphol., 41(1)*:268-277, 2023.

RESUMEN: La estimación del sexo es un aspecto importante de la identificación esquelética. Estudios previos han encontrado que la estimación del sexo de cada raza es diferente. Por lo tanto, es necesario desarrollar ecuaciones de funciones discriminantes para la estimación del sexo de la población tailandesa. Este estudio tuvo como objetivo investigar la relación entre el ancho, el largo y la altura de los huesos calcáneo y talus con respecto al sexo y comparar la efectividad de la estimación del sexo entre el calcáneo solo, el talus solo y entre el calcáneo y el talus. Se utilizaron un total de 200 huesos de individuos adultos (100 hombres y 100 mujeres), cuyas edades oscilaron entre 19 y 94 años. Se midieron trece variables del calcáneo y diez variables del talus. Los autores crearon ecuaciones de funciones discriminantes para la estimación del sexo y probaron la eficiencia de ellas usando un grupo de prueba de huesos de 40 individuos (20 hombres y 20 mujeres). Al analizar los valores medios de las variables en el calcáneo y el talus, se demostró que los huesos de los hombres eran significativamente diferentes al de las mujeres ($p<0,05$). Con excepción de la variable Distancia Interarticular Inferior Mínima (MinIID) en huesos talus izquierdo y derecho, la media de las variables de los huesos de los hombres y de las mujeres no fue significativamente diferente ($p>0.05$). Se utilizó un método paso a paso para crear 6 ecuaciones para la estimación del sexo. Las ecuaciones se clasificaron entre el calcáneo solo, el talus solo y entre el calcáneo y el talus, lo que proporcionó una precisión de estimación del sexo de entre 88,5 y 93,0 %. Usando el grupo de prueba, se demostró que las ecuaciones de funciones discriminantes del calcáneo solo, el talus solo y el calcáneo y el talus juntos pueden estimar el sexo con un alto nivel de precisión. La precisión de la estimación del sexo fue superior al 85 % en todas las ecuaciones. Por lo tanto, las ecuaciones de la función discriminante del calcáneo solo, el talus solo y entre el calcáneo y el talus de este estudio se pueden aplicar a la población tailandesa.

PALABRAS CLAVE: Estimación del sexo; Calcáneo; Talus; Tailandia.

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