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Metric and Comparative Analysis of Sexual Dimorphism in the Thai Femur

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ABSTRACT: Identification of sex from the skeleton is an important demographic assessment in medicolegal investigations. Studies have demonstrated that populations differ from each other in size and proportions and that these differences can affect the metric assessment of sex. It is therefore vital to determine if population differences are great enough to necessitate group-specific standards. To date, there have been no attempts to create standards of assessment for modern Thais. Therefore the purpose of this research is to establish standards from which to determine sex from the femur using a new skeletal collection housed at the Chiang Mai University Department of Anatomy. The sample is composed of 104 individuals (70 males, 34 females). Six standard osteometric dimensions including maximum length, maximum head diameter, midshaft circumference, midshaft anterior-posterior and transverse diameters, and bicondylar breadth were measured and analyzed by stepwise discriminant function statistics. To understand population differences, formulas derived from Chinese, South African whites and American whites and blacks using the same method and variables were tested on the Thai sample. Results indicated that maximum head diameter and bicondylar breadth are the optimal combination for sex diagnosis and yielded 94.2% accuracy. Direct analysis using predetermined single or multiple variables also revealed bicondylar breadth as the best single dimension (93.3%). In cross-tests on the Thais, the Chinese formula gave the most favorable outcome with unsatisfactory results for all other groups. The present research confirms that sexual dimorphism is better reflected in breadth dimensions than in bone length. Comparisons showed that Thais are very different metrically from whites and blacks, and although they most resemble the Chinese, these two groups are not identical. These findings underscore the need for population-specific formulas for identification of sex from the skeleton.

KEYWORDS: forensic science, forensic anthropology, physical anthropology, femur, discriminant function analysis, sex determination, human identification, Thailand, population variation

There is plentiful evidence that populations are metrically distinct, even within a race group. These population differences have been reported all over the world (1–8). Moreover, temporal differences have been demonstrated, even in relatively recent populations (e.g. (9,10)). Thus, the development of population-specific formulas from documented, contemporary skeletons is necessary.

Sex determination is one of the most important assessments in human identification, and since a complete pelvis is not always present, it is vital to be able to get as much information as possible from less obvious skeletal components such as long bones. Long bones are particularly suitable for metric analysis because they have no easily recognizable morphologic indicators of sex. In this regard, the femur has been studied most extensively. These studies have been conducted on the Chinese (11–14), Indians (15), Japanese (16), American Indians (17,18), European whites (19–26), Africans (27,28), and North American blacks and whites (29–31). These studies indicate that breadth and circumference dimensions tend to be more dimorphic than those of length. They all point out the need to recognize that there are significant size differences between populations.

To date, the literature contains no evidence of metric analyses of sexual dimorphism from the long bones of Southeast Asian populations (32). Standards based on other more widely studied Mongoloids such as the Chinese and Japanese may not be applicable to neighboring regions because many studies have uncovered significant differences between South and Southeast Asians (e.g., (33–35)). Therefore, the purpose of this paper is to conduct a discriminant function analysis of sexual dimorphism in the Thai femur and establish standards for these people. The Thai data are then compared with data similarly derived from North American, African, and East Asian samples and then tested using functions derived from them to determine if population specific sexing formulas are necessary.

Materials and Methods

The database ($N = 104$) consisted of 70 males and 34 females. These individuals died at Chiang Mai University Hospital between 1993 and 1996 (32). The mean age was 63.3 years (ranging from 32 to 88) for males, and 58.9 years (18 to 90) for females. These willed remains were residents of Chiang Mai or adjacent villages. Occupations varied widely—farmer, civil servant, teacher, retiree—and these individuals generally fell in the lower middle to middle socioeconomic range.

Skeletalization, carried out in the Anatomy Department, began by dismembering and defleshing. The bones were then wrapped in plastic netting, and buried in a sand-filled concrete container of approximately 30 × 1 × 1 m. Equally spaced along the unit are faucets that continuously drip water into the sand. Each burial was marked with a stake and cloth flag containing the individual's name and date of death. Burials were left in the sand for at least four months or until the bones were clean. The bones were then removed from the netting, and placed on metal sheets to air-dry. When dried, each bone was labeled with its accession number, and the hands and feet were articulated with copper wire. Each individual was stored in a plastic bag along with its cloth flag.

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The following six standard femoral dimensions (taken by senior author) were used in this analysis (4,36):

Maximum length—maximum length from the head to the medial condyle measured with an osteometric board.

Vertical head diameter—maximum diameter of the femoral head.

Midshaft circumference—circumference at the midshaft, steel tape following the contour of the bone.

Midshaft antero-posterior diameter—antero-posterior dimension at the midshaft.

Midshaft transverse diameter—transverse dimension at the midshaft.

Bicondylar breadth—maximum width between the epicondyles.

TABLE 1—*Means, standard deviations and univariate F-ratios of the Thai femur.*

Variable, (mm)	Males ($N = 70$)		Females ($N = 34$)		
	Mean	SD	Mean	SD	F-Ratio*
Max. length	429.4	21.38	397.0	19.60	55.11
Max. head dia.	45.1	1.98	39.3	1.93	195.50
A-P midshaft dia.	27.8	2.46	24.7	1.76	44.97
Trans midshaft dia.	25.3	1.97	23.3	2.78	18.71
Bicondylar br.	79.7	3.63	70.0	3.30	171.60
Midshaft circ.	83.7	4.70	75.4	5.49	62.99

* Degrees of freedom = 1,101. All significant at $p < 0.001$.

TABLE 2—*Stepwise discriminant function analysis of the femur.**

Step	Variables	Wilks' Lambda	Equiv. F-ratio	d.f.†
1	Max. head dia.	0.34059	195.55	1,101
2	Bicondylar br.	0.31318	171.59	2,100

* Variables not selected into the stepwise analysis include max. length, A-P midshaft dia., trans midshaft dia., and midshaft circ.

† d.f. = discrimination function.

Measurements (in mm) were taken from the left side, whenever possible, using a sliding caliper, an osteometric board, and steel tape. Specimens with obvious gross pathologic lesions were excluded. Data were analyzed using various subroutines of a mainframe version of SPSSX (37). Stepwise analysis was used to select the combination of variables that best discriminate between the sexes (with $F = 1.0$ to enter and $F = 1$ to remove). In addition, selected variables, alone and in combination, were subjected to direct discriminant function analysis to develop formulas to allow sex determination from fragmentary remains.

To assess population differences, Thai measurements were compared with those from Chinese (14), American blacks and whites (31), and South African whites (28) using a t-test. Cross-population tests were then carried out on the Thai sample using the most accurate formulas derived from each of the aforementioned groups. These comparative works were chosen because of their geographic diversity and methodological comparability. All used stepwise discriminant function statistics on the same six dimensions.

Results

Table 1 lists descriptive statistics. Male values are greater than those of females in all dimensions and the differences are statistically significant at $p < 0.001$. The results of the stepwise procedure appear in Tables 2 and 3 (Function 1). Of the six measurements entered into the analysis, only maximum head diameter and bicondylar breadth are selected as the optimal combination for sex determination. The univariate F-ratio analyzes the variance within and between the sexes, while Wilks' lambda calculates the diagnostic strength of a given variable and determines the order in which the variables are selected to enter the function (Table 2). Table 3 contains the canonical discriminant coefficients produced by the stepwise discriminant function analysis. The standardized coefficient indicates the relative contribution of each dimension to the function, and the structure coefficient is the intercorrelation between the predictor variables and the discriminant score. It is clear that maximum head diameter makes the greatest contribution to the function (Table 3). The raw coefficients are the variable weights used to calculate a discriminant score.

A discriminant score is obtained by multiplying each dimension

TABLE 3—*Canonical discriminant function coefficients and group centroids for males and females.*

Functions and Variables	Raw Coefficient	Standardized Coefficient	Structure Coefficient	Group Centroids
Stepwise analysis				
1 Max. head dia.	0.3229101	0.64	0.94	M = 1.0294
Bicondylar br.	0.1298626	0.46	0.88	F = −2.0891
Constant	−23.86411			
Sectioning point	−0.52985			
Direct analysis				
2 Max. head dia.	0.4760232	0.94	0.99	M = 0.9729
Midshaft circ.	0.0246287	0.12	0.56	F = −1.9744
Constant	−22.53586			
Sectioning point	−0.50075			
3 Midshaft circ.	0.0327514	0.16	0.60	M = 0.9154
Bicondylar br.	0.2584708	0.91	0.99	F = −1.8578
Constant	−22.41300			
Sectioning point	−0.47120			
4 Max. head dia.				
Demarking point	Females < 42.18 < Males			
5 Midshaft circ.				
Demarking point	Females < 79.55 < Males			
6 Bicondylar br.				
Demarking point	Females < 74.81 < Males			

by its raw coefficient and adding them together along with the constant. For example, the discriminant score (DS) for Function 1 is calculated as follows:

$$0.3229101(\text{maximum head diameter}) + 0.1298626(\text{bicondylar breadth}) - 23.86411 = \text{DS}$$

using the dimensions of a bone to be sexed. If the score is greater than the sectioning point, the individual is considered male; a lower score, female. The farther the discriminant score is from the sectioning point, the higher the probability of correct identification (posterior probability).

Several direct discriminant function formulas are also generated to determine sex from fragmentary femoral remains (Table 3, Functions 2–6). When a single variable is used (Functions 4–6, Table 3), two approaches are possible. Discriminant function coefficients are provided to calculate a discriminant score, but it is easier to simply compare the dimension of the specimen in question to a demarking point. The demarking point is the simple average of the means for each each sex. A higher value identifies a person as male, a lower one, female.

TABLE 4—*Sexing accuracy using combined and individual variables.*

Functions and Variables	N	Males %	Males N*	Females %	Females N	Average
Stepwise analysis						
1 Max. head dia. Bicondylar br.	103	94.2	65/69	94.1	32/34	94.2
Direct analysis						
2 Max. head dia. Midshaft circ.	103	89.9	62/69	94.1	32/34	91.3
3 Midshaft circ. Bicondylar br.	104	91.4	64/70	94.1	32/34	92.3
4 Max. head dia.	103	88.4	61/69	97.1	33/34	91.3
5 Midshaft circ.	104	88.6	62/70	79.4	27/34	85.6
6 Bicondylar br.	104	94.3	66/70	91.2	31/34	93.3

* Ratio of cases correctly classified by a given function.

Overall combined accuracies for both sexes using multiple variables (Functions 1–3) spanned 91.3 to 94.2% Table 4. The best separation (94.2%) is produced by Function 1 generated by the stepwise procedure. The mean accuracies from single variables (Functions 4–6) range from 85.6 to 93.3%. Bicondylar breadth provided the highest separation for a single variable in males at 94.3% while maximum head diameter produces 97.1% accuracy in females (Table 4). While these percentages indicate high accuracy, the application of these formulas to different samples would likely yield somewhat lower accuracy values.

Interpopulation variation is assessed by comparing Thais with Chinese, South African whites, and American whites and blacks (Table 5). It is clear that Thais are smaller in all femoral dimensions. The difference is statistically significant in all of the non-Asian samples. Overall, Thais are most similar to the Chinese. Table 6 lists the results of cross-testing the Thai data using formulas derived from the comparative samples and contrasting them with accuracies obtained from those original studies. Formulas from Americans and South Africans have identified most Thais as females, thus reflecting the one to two standard deviation differences between most dimensions as shown in Table 5. Only 27% of Thai males are correctly sexed by the South African white formula. Although the best results are from the Chinese derived formula (87.1% in males and 94.1% in females) (Table 6), they are lower than the accuracy obtained on Thais using their population specific standards (94.2 and 94.1%, respectively).

Discussion

The results of this study confirm that the Thai femur is a good skeletal component from which to determine sex, with classification accuracy reaching 94.2%. Stepwise discriminant function analysis selected two (of six) dimensions, head diameter and epicondylar breadth, to achieve this separation. These are also the best single measurements—at over 91 and 93%, respectively (Table 4). Neither of these results is significantly lower than their

TABLE 5—*Means, and standard deviations for Thai and four comparative populations.*

Variables	Thai Mean	Thai SD	Chinese* Mean	Chinese* SD	S. African Whites† Mean	S. African Whites† SD	Amer. Whites‡ Mean	Amer. Whites‡ SD	Amer. Blacks‡ Mean	Amer. Blacks‡ SD
MALES										
	(N = 70)		(N = 37)		(N = 56)		(N = 56)		(N = 50)	
Max. length	429.4	21.38	442.2	22.90	469.7	27.97	451.6	23.44	477.7	25.12
Max. head dia.	45.1	1.98	46.2§	2.62	48.5	2.65	48.2	2.52	47.8	2.39
Midshaft circ.	83.7	4.70	85.3§	6.36	93.2	6.10	91.1	4.72	91.1	6.08
A-P midshaft dia.	27.8	2.46	28.0§	2.56	31.3	2.61	29.0	2.62	29.9	3.07
Trans midshaft	25.3	1.97	25.6§	2.76	29.1	2.20	29.0	2.69	28.2	3.01
Bicondylar br.	79.7	3.63	80.3§	4.27	84.6	4.63	83.0	4.10	83.2	3.99
FEMALES										
	(N = 34)		(N = 39)		(N = 50)		(N = 54)		(N = 51)	
Max. length	397.0	19.60	401.0§	19.71	437.6	20.65	425.1	23.61	437.3	23.73
Max. head dia.	39.3	1.93	41.1	2.64	43.0	2.42	42.2	2.28	42.0	2.33
Midshaft circ.	75.4	5.49	75.5§	4.42	84.7	5.46	82.1	5.28	82.5	5.00
A-P midshaft dia.	24.7	1.76	24.4§	1.93	28.2	2.50	26.1	2.35	27.1	2.04
Trans midshaft	23.3	2.78	23.2§	2.24	26.3	1.67	26.0	2.15	25.2	2.03
Bicondylar br.	70.0	3.30	70.6§	3.20	75.1	3.32	74.1	3.66	74.0	3.64

* (14).
† (28).
‡ (31).
§ Not statistically significant. All others significant at the $p < 0.05$ level.

TABLE 6—*Cross-test of sex determination accuracy using discriminant function formulas derived from four geographically diverse populations.**

Cross-validation and Comparative Group	Total N	Male		Female		Dimensions in Function
		%	N	%	N	
Present study	103	94.2	65/69	94.1	32/34	Head dia. + Bicondylar br.
Chinese formula on Thais	104	87.1	61/70	94.1	32/34	Bicondylar br. +
Chinese (original study)	(78)	(92.3)	(36/39)	(92.3)	(36/39)	A-P dia. + Max. length
S Afr white formula on Thais	104	27.1	19/34	100.0	34/34	Head dia. +
S Afr white (original study)	(105)	(85.7)	(48/56)	(91.8)	(45/49)	Trans. dia. Bicondylar br.
Am white formula on Thais	104	44.3	31/70	100.0	34/34	Head dia. +
Am white (original study)	(101)	(91.1)	(51/56)	(92.6)	(50/54)	Max. length Bicondylar br. + Midshaft circ.
Amer black formula on Thais	104	65.7	46/70	100.0	34/34	Head dia. +
Amer black (original study)	(103)	(92.0)	(46/103)	(93.4)	(57/103)	Max. length Bicondylar br. + Midshaft circ. + Max. length

* The following discriminant function formulas were used in this cross-testing: Chinese (14) F = 0.20277340*Bicondylar br. + 0.01041030*Max. length + 0.08912650*A-P midshaft dia. −21.98602.

American Todd white (31) F = 0.30829*Max. head dia. + 0.08253*Bicondylar br. −0.01607*Max. length + 0.07202*Midshaft circ. −19.63418.

American Todd black (31) F = 0.23925*Max. head dia. + 0.16595*Bicondylar br. + 0.00724*Max. length −0.07869*Midshaft circ. +0.07509*A-P midshaft dia. −22.26742.

South African white (28) F = 0.16363890*Max. head dia. +0.09093376*Trans midshaft dia. +0.13420310*Bicondylar br. −20.80771.

combined accuracy and this is an important factor in the sex determination of fragmentary remains. It should be noted, however, that there is a noticeable gap in accuracy between the sexes in two out of three single-dimension assessments. The proximal dimension is more diagnostic in females while the midshaft is a better indicator in males. The distal end is best in males, but not much lower in females. Differences in accuracy between the sexes can result from variation in sample size, and more importantly, intrasex variability.

As noted earlier, the present findings agree with previous studies of long bones in several populations that found that circumference and breadth dimensions provide the greatest separation of the sexes (see (4)). Not only was length a less effective discriminator in this and all other work, but it was rarely even selected to take part in a stepwise discriminant function. Interestingly, in many earlier studies, the most dimorphic areas, namely the head and distal epiphysis were not measured. Drawing from the literature (38–40), Black (17) suggested that the differential bone remodeling that exists between males and females led to greater cortical bone developed in males during adolescence and remains essentially unchanged throughout adulthood. This differential cortical development has its maximum impact on breadth and circumference measurements. Others took a functional approach to explain the results of their studies, suggesting that midshaft circumference, and distal and proximal measurements are better indicators of sex because the functional demands of weight and musculature concentrate on these parts of the bone (27,29).

In the present study, population variation is graphically illustrated by the statistically significant differences in femur dimensions between Thais and the comparative samples (Table 5). It is therefore not surprising that there are differences in the combinations of variables incorporated into the functions even though (as mentioned previously) the same initial set of variables was used for discriminant function analysis in each group. As can be seen in Table 6, the only measurement common to all five samples is bicondylar breadth. Femoral head diameter is included in all but the Chinese. In contrast to earlier conclusions on the importance of midshaft circumference, this dimension was only a factor in the American samples.

When populations were compared, it was not surprising that the best results for a foreign derived formula was that of the Chinese function on Thais. First, both are Mongoloids and the Chinese are the geographically closest test group to the Thais. Moreover, of the three dimensions used in the Chinese function, the two variables that contribute the most—bicondylar breadth and midshaft A-P—were not significantly different. Ironically, femoral head diameter was a strong indicator of dimorphism in the Thais (and all the other groups, for that matter), but was not even selected by the Chinese function. Thus, while the results of using the Chinese formula on Thais yields adequate separation (87.1% for males and 94.1% for females), it is not because these two Asian populations are homogeneous or interchangeable. In addition, there are varying degrees of difference in different parts of the skeleton, for example, there may be more population variability in the cranium than the limbs. King (32) observed this when he compared the skeletons of Thais with Chinese from Hong Kong. This is consistent with numerous studies of biological distance in this region which revealed significant differences between East and Southeast Asians (e.g., (35)).

Osteometric analysis, with the use of discriminant function statistics, has become one of the most common means to assess sexual dimorphism. As demonstrated here, this method also indirectly reveals population variation by comparing tests of formulas derived from one group on another. However, it is important to make comparisons based on works that rely on the same methodology using the same dimensions. All studies compared here included the same six measurements and the sexing formulas were generated by the stepwise approach in which all variables were selected by the statistical program. Thus, the comparability of these studies allows a valid assessment of population variation. With this in mind, the results of the present study leave no doubt that metric analysis must be specific to diverse populations.

Osteometry has become a popular choice for sex determination because it is relatively simple to learn and is particularly suitable for long bones where interobserver error is a minimal problem. The most serious problems in applying it may arise from small sample sizes and skewed distributions of the sexes. For example, of the 104 individuals in this Thai sample, only 34 (33%) are female. Stepwise discriminant function analysis is a powerful tool for metric evaluation because its multivariate approach to sex diagnosis gives a more complete picture than simply measuring a number of individual dimensions with no appreciation of their interdependence. However, in this type of prediction statistics, a small sample size may exaggerate diagnostic accuracy. Unfortunately, this problem has stymied attempts to develop population-specific metric standards because of the lack of large documented skeletal collections like Hamann-Todd, Terry (both in the U.S.), and Dart (South Africa). The present research, which produced the first standards for Thais, was only possible because of the very recent curation of these remains. Therefore, although these new standards are useful in determining sex from the femur in Thais, osteologists must remain aware that the true nature of sexual variation in a population may not be fully revealed in a relatively small sample.

In conclusion, the comparative approach taken in this study has yielded strong evidence of the need for population-specific standards by actually quantifying the results of cross-testing formulas derived from one group on another. The present research joins the ranks of many others that have demonstrated that osteometric assessments are very sensitive to population variation. This is a vital consideration in medicolegal matters.

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