

Sexual dimorphism in the humerus: A comparative analysis of Chinese, Japanese and Thais

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Abstract

Determination of sex from the skeleton is vital to medicolegal investigations. There is no longer any question that populations differ in size and proportions and these differences affect the metric assessment of sex. The extent of variation in sexual dimorphism among Asian Mongoloids within and between regions has not been quantified by discriminant function analysis, nor have standards for most groups been introduced for the humerus. Therefore, the purpose of this research is to establish metric standards for sex determination from the humerus of Chinese, Japanese and Thais, as well as to compare size and sexual dimorphism in these Asian Mongoloid populations. The database for this study consisted of documented skeletal samples from China ($N=87$), Japan ($N=90$), and Thailand ($N=104$). Six standard dimensions, including maximum length, vertical head diameter, minimum midshaft diameter, maximum midshaft diameter, midshaft circumference, and epicondylar breadth were taken and subjected to stepwise and direct discriminant function analysis. Of dimensions selected by the stepwise function, vertical head diameter and epicondylar breadth were the only elements common to all these groups. Overall, mean accuracies were highest using formulae produced by the stepwise procedure and ranged from 86.8% in the Chinese to 92.4% in the Japanese to 97.1% in the Thais. Group comparisons also revealed that while the Chinese had the largest measurements, they were the least dimorphic. The reverse was true for the Thais and the Japanese were intermediate on both counts. In cross validation tests,

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classification accuracy decreased in all cases where a formula from one group was applied to another. It was therefore concluded even though all individuals were Asian Mongoloids, these regionally diverse populations exhibited significant metric differences that affect sex determination from the skeleton. These findings confirm those of previous studies that there is a need for group specific metric standards of assessment. © 1998 Elsevier Science Ireland Ltd. All rights reserved.

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1. Introduction

Since osteometric methods for the determination of sex from the skeleton are population specific, researchers from around the world have conducted studies to establish group specific standards of assessment [1]. Just as variation has been found both within and between European and American populations for example, Asians, too, have been shown to exhibit significant regional differences [2–4]. Numerous cranial and postcranial sexing studies have emerged from East Asia, including those on Japanese [5–12] and Chinese skulls [13–23]. Postcranial work in Japan encompasses the scapula, femur and tibia [5,6,24–27] as well as the sacrum and pelvis [28,29]. Similar studies were also conducted on Chinese long bones [30–39,39] and pelvis [33,40] and even on the patella [41]. In comparison, studies resulting in the production of sexing standards from Southeast Asia are very limited [42–44] and none have been published on the humerus.

Recent work has revealed size differentials between Thais and Chinese from Hong Kong. King and associates [45] observed that Thais are smaller than East Asians such as the Chinese, and the most significant difference between them is femur length. Although Thais are shorter, shaft and epiphyseal diameters are comparable, suggesting relatively greater robusticity. Moreover, the selection of different femoral dimensions by the stepwise discriminant function for each population indicated that sexual dimorphism is concentrated in different portions of this bone. In Asia, the humerus has rarely been tapped as a site for sex determination even though it has often demonstrated even greater diagnostic accuracy than other long bones, including the femur [37,46,47]. Therefore, the purpose of this research is to establish metric standards for the determination of sex from the humerus of Chinese, Japanese and Thais, as well as to compare size and sexual dimorphism in these regionally diverse Asian Mongoloid populations.

2. Materials and methods

The database for this study consisted of documented skeletal samples from China, Japan, and Thailand. The Chinese skeletal remains were excavated from cemeteries near the cities of Qingdao (Shandong) and Chang Chun (Liaoning) [39]. The collection contained 87 relatively complete, well-preserved, adult skeletons of known sex who died

as recently as the 1930s. The Japanese series is located at Jikei Medical University, Tokyo, and is composed of about 90 skeletons [12,27]. Although some bones were not available, preservation was excellent. The sample consisted of adults obtained from the anatomy department where they were collected between 1960 and 1970, and was predominantly comprised of individuals who lived through the second World War. The Thai sample has 104 individuals from Chiang Mai or adjacent villages who died at Chiang Mai University Hospital between 1993 and 1996 [44].

A total of six humeral dimensions were taken (to the nearest millimeter and from the left side when possible) using an osteometric board, sliding caliper, and steel tape. Measurements include maximum length, vertical head diameter, minimum midshaft diameter, maximum midshaft diameter, midshaft circumference, epicondylar breadth and were taken according standard procedure [1,48,49]. Specimens with obvious pathologies were not included in the study.

To assess population differences, measurements from the Chinese, Japanese, and Thais were compared using a *t*-test. Data were then analyzed with a mainframe SPSSX program [50]. Stepwise discriminant function analysis (Method=Wilks with $F=1.0$ to enter and $F=1$ to remove) was used to select the combination of variables that best discriminate between the sexes. When male and female sample sizes differed, sectioning points were calculated by averaging the group centroids. In addition, selected variables, alone and in combination, were subjected to direct discriminant function analysis to develop formulae to determine sex from fragmentary remains. When single dimensions were used, a demarking point was calculated as the average of the group means. Cross-population tests were then carried out between all of the samples using the stepwise formula derived from one sample on the others.

3. Results

Table 1 presents descriptive statistics for all three samples. All male dimensions are significantly greater than those of females ($P<0.001$). The Student's *t*-test in Table 2 indicates that significant differences vary both by population and sex. Overall, the Chinese have the largest average dimensions, especially in maximum length. By region, the only significant difference between the East Asians (Chinese and Japanese) was maximum length which is longer in Chinese males. In contrast, six dimensions were significantly different between the East Asian Chinese and Southeast Asian Thais, but only midshaft circumference was significantly varied in both sexes. Similarly, a total of five significantly different measurements were detected in the other Southeast Asian/East Asian comparison of Thai and Japanese males and females, but these were mostly limited to midshaft dimensions and all were larger in the Japanese. The only dimension that exhibited no significant differences was epicondylar breadth.

The stepwise discriminant function analyses for each population appears in Table 3. Different combinations of the six measurements were selected by the function in all three samples. Four variables were selected for the Chinese and Japanese, and three were included for the Thais (Table 3). The only dimensions common to all groups were epicondylar breadth and vertical head diameter. Interestingly, these most consistently

Table 1
Means standard deviations and univariate *F*-ratios of humeral dimensions in Chinese, Japanese, and Thais

Variables (mm)	Males		Females		<i>F</i> -ratio ^a		
	Mean	SD	Mean	SD			
<i>Chinese</i>							
	<i>N</i>					41	33
Max. length	313.7	16.46	283.6	13.68	70.91		
Vertical head diameter	44.9	2.77	39.7	2.54	70.09		
Midshaft circumference	64.3	5.09	57.9	6.36	22.80		
Min. midshaft diameter	17.0	2.14	15.0	1.78	18.83		
Max. midshaft diameter	22.0	2.20	19.6	2.11	23.02		
Epicondylar breadth	60.4	8.65	52.3	3.20	26.07		
<i>Japanese</i>							
	<i>N</i>					44	35
Max. length	297.4	10.42	276.9	17.10	43.13		
Vertical head diameter	44.1	1.75	39.1	2.57	103.30		
Midshaft circumference	65.5	4.78	57.3	5.29	53.33		
Min. midshaft diameter	17.6	1.39	15.7	1.69	45.29		
Max. midshaft diameter	22.7	1.83	19.9	1.85	54.64		
Epicondylar breadth	59.8	2.27	52.1	3.79	122.25		
<i>Thai</i>							
	<i>N</i>					70	34
Max. length	300.6	15.65	278.9	13.67	47.34		
Vertical head diameter	44.4	2.11	38.2	2.34	179.90		
Midshaft circumference	61.2	3.74	53.1	4.00	102.50		
Min. midshaft diameter	16.7	2.18	13.9	1.39	46.96		
Max. midshaft diameter	21.3	1.64	19.3	3.50	15.71		
Epicondylar breadth	60.3	2.92	52.1	2.28	204.40		

^aAll significant at $P < 0.001$ with d.f. = 72 for Chinese; 77 for Japanese; and 102 for Thais.

dimorphic areas showed the least population variation (Table 2). Table 4 displays the canonical coefficients and constants produced by the analyses of all groups. Function 1 contains values generated by the stepwise procedure. The direct discriminant approach was then used to determine the diagnostic accuracy of individual and combined variables (that can be useful in sexing a fragmentary bone), and these appear as Functions 2 through 7. The standardized coefficient quantifies the contribution of a given variable to overall classification, while the structure coefficient analyzes the correlation between the variables and the function. To calculate the discriminant score from Function 1 for Thais (Table 4), simply multiply each dimension by its coefficient and add them together along with the constant as follows:

$$0.2215440(\text{epicondylar breadth}) + 0.2160145(\text{vertical head diameter}) -$$

$$0.0820202(\text{midshaft circumference}) - 23.21353(\text{constant}) = \text{Discriminant Score}$$

The score is then compared with the sectioning point (-0.58185) to determine which

Table 2
Student's *t*-test and level of significance between the means in Chinese, Japanese, and Thais

	Males		Females	
	<i>t</i>	<i>P</i>	<i>t</i>	<i>P</i>
<i>Chinese and Japanese</i>				
Max. length	5.49	0.001	1.77	0.081
Vertical head diameter	1.68	0.096	0.90	0.370
Midshaft circumference	-1.18	0.243	0.48	0.633
Min. midshaft diameter	-1.34	0.185	-1.57	0.122
Max. midshaft diameter	-1.51	0.135	-0.58	0.561
Epicondylar breadth	0.49	0.626	0.19	0.852
<i>Chinese and Thai</i>				
Max. length	4.19	0.001	1.40	0.167
Vertical head diameter	1.20	0.233	2.45	0.017
Midshaft circumference	3.62	0.001	3.70	0.001
Min. midshaft diameter	0.85	0.400	2.95	0.004
Max. midshaft diameter	2.02	0.046	0.45	0.653
Epicondylar breadth	0.10	0.922	0.22	0.825
<i>Japanese and Thai</i>				
Max. length	-1.18	0.242	-0.54	0.594
Vertical head diameter	-0.74	0.464	1.52	0.133
Midshaft circumference	5.37	0.001	3.63	0.001
Min. midshaft diameter	2.39	0.019	4.85	0.001
Max. midshaft diameter	4.24	0.001	0.89	0.375
Epicondylar breadth	-1.06	0.290	-0.01	0.989

Table 3
Stepwise discriminant function analysis of the Chinese, Japanese and Thai humerus^a

Step	Variables entered	Wilks lambda	Equiv. <i>F</i> -ratio	d.f.
<i>Chinese</i>				
1	Max. length	0.50383	70.91	1,72
2	Vertical head diameter	0.44867	43.62	2,71
3	Epicondylar breadth	0.43062	30.85	3,70
4	Midshaft circumference	0.41816	24.00	4,69
<i>Japanese</i>				
1	Epicondylar breadth	0.38645	122.25	1,77
2	Vertical head diameter	0.34727	71.42	2,76
3	Min. midshaft diameter	0.34074	48.37	3,75
4	Midshaft circumference	0.32081	39.17	4,74
<i>Thai</i>				
1	Epicondylar breadth	0.33286	204.43	1,102
2	Vertical head diameter	0.28772	125.02	2,101
3	Min. midshaft diameter	0.28285	84.51	3,100

^a All six variables were included in the analysis.

Table 4
Canonical discriminant function coefficients for the humerus in Chinese, Japanese, and Thai samples

Functions and variables		Raw ^a coefficient	Standard coefficient	Structure coefficient	Group centroids
Chinese					
<i>Stepwise analysis</i>					
1	Max. length	0.0411495	0.63	0.84	M=1.0439
	Vertical head diameter	0.1970659	0.53	0.84	F= -1.2969
	Epicondylar breadth	0.0499184	0.34	0.51	
	Midshaft circumference	-0.0524754	-0.30	0.48	
	Constant	-20.36060			
	Sectioning point	-0.12650			
<i>Direct analysis</i>					
2	Vertical head diameter	0.3221408	0.86	0.96	M=0.9094
	Epicondylar breadth	0.0437006	0.30	0.59	F= -1.1299
	Constant	-16.20353			
	Sectioning point	-0.11025			
3	Vertical head diameter	0.3820897	1.02	0.99	M=0.8735
	Midshaft circumference	-0.0062366	-0.04	0.57	F= -1.0852
	Constant	-15.89166			
	Sectioning point	-0.10585			
4	Epicondylar breadth	0.0950590	0.65	0.86	M=0.6208
	Midshaft circumference	0.0977436	0.56	0.80	F= -0.7713
	Constant	-11.40636			
	Sectioning point	-0.07525			
5	Vertical head diameter	Male >42.6> Female			
6	Midshaft circumference	Male >61.5> Female			
7	Epicondylar breadth	Male >56.8> Female			
Japanese					
<i>Stepwise analysis</i>					
1	Vertical head diameter	0.2396615	0.52	0.80	M=1.2812
	Min midshaft diameter	-0.3620515	-0.55	0.43	F= -1.6106
	Epicondylar breadth	0.2100037	0.64	0.87	
	Midshaft circumference	0.0953087	0.48	0.57	
	Constant	-21.71991			
	Sectioning point	-0.16470			
<i>Direct analysis</i>					
2	Vertical head diameter	0.2222240	0.48	0.92	M=1.2072
	Epicondylar breadth	0.2136390	0.65	0.84	F= -1.5176
	Constant	-21.35581			
	Sectioning point	-0.15520			
3	Vertical head diameter	0.3864432	0.83	0.97	M=1.0499
	Midshaft circumference	0.0552263	0.28	0.70	F= -1.3199
	Constant	-19.60852			
	Sectioning point	-0.13500			

Table 4. Continued

Functions and variables	Raw ^a coefficient	Standard coefficient	Structure coefficient	Group centroids	
4	Epicondylar breadth	0.2793073	0.85	0.97	M=1.1474
	Midshaft circumference	0.0561238	0.28	0.64	F= -1.4425
	Constant	-19.21984			
	Sectioning point	-0.14755			
5	Vertical head diameter	Male >41.9> Female			
6	Midshaft circumference	Male >61.9> Female			
7	Epicondylar breadth	Male >56.4> Female			
Thai					
<i>Stepwise analysis</i>					
1	Epicondylar breadth	0.2215440	0.60	0.89	M=1.0990
	Vertical head diameter	0.2160145	0.47	0.83	F= -2.2627
	Min. midshaft diameter	0.0820202	0.16	0.43	
	Constant	-23.21353			
	Sectioning point	-0.58185			
<i>Direct analysis</i>					
2	Vertical head diameter	0.2343809	0.51	0.90	M=1.0860
	Epicondylar breadth	0.2310283	0.63	0.84	F= -2.2358
	Constant	-23.24487			
	Sectioning point	-0.57490			
3	Vertical head diameter	0.3599955	0.79	0.95	M=0.9638
	Midshaft circumference	0.0912803	0.35	0.72	F= -1.9842
	Constant	-20.60002			
	Sectioning point	-0.51020			
4	Epicondylar breadth	0.3018484	0.82	0.96	M=1.0149
	Midshaft circumference	0.0794679	0.30	0.68	F= -2.0894
	Constant	-22.05343			
	Sectioning point	-0.53725			
5	Vertical head diameter	Male >42.4> Female			
6	Midshaft circumference	Male >58.6> Female			
7	Epicondylar breadth	Male >57.5> Female			

^aDiscriminant score is calculated from raw coefficients.

Discriminant score less than the sectioning point classifies as female.

Single variable less than the demarking point classifies as female.

sex the specimen belongs to. A score greater than the sectioning point classifies as male; a lower score as female. When a single variable is used, a demarking point (the group mean) is provided (Table 4). Overall, mean accuracies were highest using formulae produced by the stepwise procedure and ranged from 86.8% in the Chinese to 97.1% in the Thais (Table 5). This reveals that even though the Chinese are the largest of these groups, they are the least dimorphic. By sex, Chinese and Thai females are generally better diagnosed than males, while the reverse is true for the Japanese. Epicondylar

Table 5
Sexing accuracy using combined and individual variables

Functions and variables	N	Males		Females		Average	
		%	N ^a	%	N		
Chinese							
<i>Stepwise analysis</i>							
1	Max. length Vertical head diameter Epicondylar breadth Midshaft circumference	76	85.4	35/41	88.6	31/35	86.8
<i>Direct analysis</i>							
2	Vertical head diameter Midshaft circumference	82	79.1	34/43	82.1	32/39	80.5
3	Vertical head diameter Epicondylar breadth	77	81.0	34/42	82.9	29/35	81.8
4	Epicondylar breadth Midshaft circumference	77	69.0	29/42	88.6	31/35	77.9
5	Vertical head diameter	82	79.1	34/43	82.1	32/39	80.5
6	Midshaft circumference	82	69.8	30/43	84.6	33/39	76.8
7	Epicondylar breadth	77	71.4	30/42	85.7	30/35	77.9
Japanese							
<i>Stepwise analysis</i>							
1	Vertical head diameter Min. midshaft diameter Epicondylar breadth Midshaft circumference	79	95.5	42/44	88.6	31/35	92.4
<i>Direct analysis</i>							
2	Vertical head diameter Midshaft circumference	79	88.6	39/44	85.7	30/35	87.3
3	Vertical head diameter Epicondylar breadth	79	95.5	42/44	88.6	31/35	92.4
4	Epicondylar breadth Midshaft circumference	79	93.2	41/44	85.7	30/35	89.9
5	Vertical head diameter	79	90.9	40/44	82.9	29/35	87.3
6	Midshaft circumference	79	77.3	34/44	82.9	29/35	79.8
7	Epicondylar breadth	79	93.2	41/44	85.7	30/35	89.9
Thai							
<i>Stepwise analysis</i>							
1	Vertical head diameter Min midshaft diameter Epicondylar breadth	104	97.1	68/70	97.1	33/34	97.1
<i>Direct analysis</i>							
2	Vertical head diameter Midshaft circumference	104	91.4	64/70	97.1	33/34	93.3
3	Vertical head diameter Epicondylar breadth	104	97.1	68/70	97.1	33/34	97.1
4	Epicondylar breadth Midshaft circumference	104	92.9	65/70	97.1	33/34	94.2
5	Vertical head diameter	104	90.0	63/70	91.2	31/34	90.4
6	Midshaft circumference	104	84.3	59/70	94.1	32/34	87.5
7	Epicondylar breadth	104	91.4	64/70	97.1	33/34	93.3

^a Ratio of cases correctly classified by a given function.

Table 6
Cross-validation of sex determination accuracy using stepwise discriminant function formulae

Cross-validation ^a and Comparative group	Total <i>N</i>	Male		Female		Dimensions in function
		%	<i>N</i>	%	<i>N</i>	
Chinese accuracy ^b Chinese formula on Japanese data	76	85.4	35/41	88.6	31/35	Max length + Vertical head diameter + Midshaft circumference + picondylar breadth
Thai data	104	0.0	0/70	100.0	34/34	
Japanese accuracy ^b Japanese formula on Chinese data	79	95.5	42/44	88.6	31/35	Vertical head diameter + Min midshaft diameter + Midshaft circumference + Epicondylar breadth
Thai data	104	90.0	63/70	94.1	32/34	
Thai accuracy ^b Thai formula on Chinese data	104	97.1	68/70	97.1	33/34	Vertical head diameter + Min midshaft diameter + Epicondylar breadth
Japanese data	84	95.7	45/47	78.4	29/37	

^a Cross-validation was carried out by applying a formula of one group to the data of the other two groups.

^b These accuracies are from Table 5.

breadth was the most discriminating single dimension in both Japanese and Thais, while head diameter was best in Chinese.

Cross population tests were conducted to evaluate the applicability of a formula developed from one group on another. Function 1, the most accurate on each sample, was used for this analysis. As can be seen in Table 6, the worst results were produced by applying the Chinese formula to the other samples. Of the 70 Thai males, not a single one was accurately identified. The Japanese did not fare much better – only three males were properly detected using Chinese standards. On average, the best discrimination was obtained by applying Japanese formula to Thais (92%). However, this was still less than the 97.1% discrimination calculated by the Thai function on Thais.

4. Discussion

The results of this study indicate that the humerus is a good bone from which to determine sex in Chinese, Japanese and Thais. It was also apparent that the degree and distribution of sexual dimorphism varied both within and between differing regions. The size of Chinese bone dimensions generally exceeded those of the Japanese and Thais, but sexing accuracy was the lowest at about 87%. In contrast, the Thais were generally smallest, but were most dimorphic achieving 97% sexing accuracy. The Japanese were intermediate in both size and diagnostic accuracy. Cross-validation tests confirmed that formulae developed from one population are less discriminating when applied to another.

For sex determination, stepwise discriminant function analysis calculates the optimal combination of variables and weights them to reflect their contribution to sex diagnosis. A formula is thus produced to maximize sexing accuracy. Many factors can affect the

outcome of this procedure. Sample size and the choice of variables can affect the results [51]. Choice of variables is also essential to allow comparability when assessing population differences as in the present study.

The most effective single dimensions as determined by direct discriminant analysis were vertical head diameter in the Chinese (81%) and epicondylar breadth in the Japanese and Thais (90% and 93%, respectively). Wu's [37] study of 20th century northeastern Chinese also reported greatest dimorphism in proximal and distal bone dimensions. He found humeral head diameter the most discriminatory at 84%. Head diameter was also the best single discriminator (90%) for prehistoric samples from California [47]. In one of the most complete studies of the humerus, France [46] assessed Caucasoid, Negroid, Sudanese Nubians, Pueblo, and Arikara skeletal samples and reached over 90% accuracy using 11 variables.

Comparisons of the results of the present study with those from other long bones of skeletons in the same samples are especially valuable because they reveal intraskeletal differences in sexual dimorphism while controlling for individual variation. In Thais, the femur yielded an average accuracy of 94% by stepwise discriminant analysis [45]; in the Chinese, it was 92% [39]. In the tibia, the Japanese attained 87% accuracy [27], while Thais reached 94% [52]. Thus, the humerus is a better predictor of sex in the Japanese and Thai samples, while the reverse was true for the Chinese femur. These comparisons also emphasize that Thais are consistently more dimorphic than their East Asian counterparts. The existence of significant Asian regional differences in biological affinities has been brought to light by numerous studies [2–4]. The present work confirms the fact that the dimensions of the two East Asian groups (Chinese and Japanese) are much more similar than either is to the Southeast Asian Thais (Table 2). It also demonstrates that these mensural similarities do not translate into formula interchangeability because of population variation in the degree and distribution of sexual dimorphism within the bone (Tables 1 and 6).

In long bone studies on various populations mentioned earlier, breadth and circumferential dimensions were generally found to be better discriminators than length [25,27,37,39,46,53–56]. This was also the case for the present research. In the stepwise functions produced here, vertical head diameter and epicondylar breadth were consistently selected for all three groups, while maximum length was only a factor in the Chinese.

France [46] concluded that proximal and distal measurements are likely to be more accurate because these areas are subjected to greater functional or occupational stress. From a somewhat different perspective, Ruff [57] reported that the cross sections of limb bones may be influenced by behavior more than bone length. It has also been claimed that stature based sexual dimorphism peaks in societies that are at the extremes of protein consumption – both high and low [58].

Another possible explanation for this phenomenon was discussed by Black [53], who proposed that differential bone remodeling exists between males and females. In addition, more cortical bone is developed during adolescence in males and the ratio remains essentially unchanged throughout adulthood. Others [59] came to a similar conclusion in their study of black femora from the Terry collection. They suggested that shape measurements are of major significance for correct diagnosis of sex because the

functional demands of weight bearing and musculature affect circumferential measurements more than length. These however, are only a few of the possible factors that could affect classification accuracy. Many researchers also noted that population affinity is a factor in sex determination [27,54,55,59,60]. For example, the length of the femur and tibia were better indicators of sex in blacks, while circumferential dimensions yielded greater accuracy for whites and Mongoloids.

In conclusion, most skeletal biologists agree that interpopulation differences necessitate the development of regionally specific standards for the identification of sex. Besides sometimes significant variation in diagnostic accuracy, population differences are apparent in the selection of variables by the function. Even when the same dimensions are chosen, the discriminant procedure quantifies the fact that the contribution of each dimension to sexing accuracy varies from one group to the next. Yet a key question remains, namely what factors lead to the differential development of sexual dimorphism in a given segment of a long bone. For example, it is not easy to explain why the humeral head differentiates sex better in one sample as opposed to epicondylar breadth in another. This study of modern Asian skeletons underscores the need for population-specific techniques, not only for medicolegal investigations, but also for the study of population affinities and factors affecting bone configurations.

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References

- [1] W.M. Krogman, M.Y. İşcan, *The Human Skeleton in Forensic Medicine*, Charles C. Thomas, Springfield, IL, 1986.
- [2] C.L. Brace, D.P. Tracer, K.D. Hunt, Human craniofacial form and the evidence for the peopling of the Pacific, *Indo-Pacific Prehist. Assoc.* 11 (1991) 247–269.
- [3] T. Hanihara, Biological relationships among Southeast Asians, Jomonese, and the Pacific populations as viewed from dental characters: the basic populations in East Asia, *J. Anthropol. Soc. Nippon* 100 (1992) 53–67.
- [4] M. Pietrusewsky, The people of Ban Chiang: an early Bronze site in Northeast Thailand, *Bull. Indo-Pacific Prehist. Assoc.* 16 (1997) 119–148.
- [5] K. Hanihara, Sexual diagnosis of Japanese long bones by means of discriminant functions, *J. Anthropol. Soc. Nippon* [Japanese with English abstract] 66 (1958) 187–196.
- [6] K. Hanihara, Sex diagnosis of Japanese skulls and scapulae by means of discriminant functions, *J. Anthropol. Soc. Nippon* 67 (1959) 191–197.
- [7] K. Hanihara, Sexing of Japanese skeleton teeth by discriminant function method, *J. Anthropol. Soc. Nippon* 89 (1981) 401–418.
- [8] H. Hoshi, Sex differences in the shape of the mastoid process in *norma occipitalis* and its importance to the sex determination of the human skull, *Okajima's Folia Anat. Jpn.* 38 (1962) 309–313.
- [9] T. Tanaka, K. Hanihara, K. Koizumu, Sex determination of the modern Japanese skull by means of discriminant function, *Sapporo Med. J.* 48 (1979) 583–593.

- [10] M. Inoue, Fourier analysis of the forehead shape of skull and sex determination by use of computer, *Forensic Sci. Int.* 47 (1990) 101–112.
- [11] M. Inoue, T. Inoue, Y. Fushimi, K. Okada, Sex determination by discriminant function analysis of lateral cranial form, *Forensic Sci. Int.* 57 (1992) 109–117.
- [12] M.Y. İşcan, M. Yoshino, S. Kato, Sexual dimorphism in modern Japanese crania, *Am. J. Hum. Biol.* 7 (1995) 459–464.
- [13] M. Bao, R. Wang, The measurements of some Chinese (Qingdao district) cranial angles (continued), *Acta Anthropol. Sinica* [Chinese with English abstract] 3 (1984) 330–333.
- [14] Z. Zhu, W. Cao, B. Lu, C. Zhang, Measurements of the arc, chord and circumference and sex-discriminating analysis in Chinese skulls, *Acta Anthropol. Sinica* [Chinese with English abstract] 4 (1985) 366–371.
- [15] R. Wang, M. Bao, The measurements of some Chinese (Qingdao district) cranial angles, *Acta Anthropol. Sinica* [Chinese with English abstract] 3 (1984) 32–36.
- [16] R. Wang, M. Bao, The measurements of some cranial angles, *Acta Anthropol. Sinica* [Chinese with English abstract] 7 (1988) 133–137.
- [17] L. Wang, A study of recent human skulls from Hong Kong assessment of sex and of regional population, *Acta Anthropol. Sinica* [Chinese with English abstract] 8 (1989) 222–230.
- [18] Y. Yang, J. Zheng, R. Dang, Y. Li, The skull of the face of Xi'an area, *Acta Anthropol. Sinica* [Chinese with English abstract] 6 (1987) 222–226.
- [19] M. Yang, L. Wu, F. Tai, Sex determination of mandible by discriminant analysis, *Acta Anthropol. Sinica* [Chinese with English abstract] 7 (1988) 329–334.
- [20] C. Li, Sex determination by skull, *J. Chinese Forensic Med.* 6 (1991) 120.
- [21] C. Li, A study on sex difference of adult skull of the northeast China: by Fourier transform, *Acta Anthropol. Sinica* 11 (1992) 312.
- [22] S. Ding, G. Ren, D. Fa, X. Yan, X. Lai, Sexual diagnosis of Chinese crania from discriminant function analysis, *Can. Soc. Forensic Sci. J.* 22 (1992) 119–122.
- [23] H. Song, Z. Lin, J. Jin, Sex diagnosis of Chinese skulls using multiple stepwise discriminant function analysis, *Forensic Sci. Int.* 54 (1992) 135–140.
- [24] T. Kimura, Sex determination on the cross-section of human lower leg bones, *Jpn. J. Legal Med.* 25 (1971) 431–438.
- [25] A. Tagaya, Interpopulation variation of sex differences: an analysis of the extremity long bone measurements of Japanese, *J. Anthropol. Soc. Nippon* 95 (1987) 45–76.
- [26] A. Tagaya, Development of a generalized discriminant function for cross-population determination of sex from long bones of the arm and leg, *Can. Soc. Forensic Sci. J.* 22 (1992) 159–176.
- [27] M.Y. İşcan, M. Yoshino, S. Kato, Sex determination from the tibia: standards for contemporary Japan, *J. Forensic Sci.* 39 (1994) 785–792.
- [28] K. Kimura, A base-wing index for sexing the sacrum, *J. Anthropol. Soc. Nippon* 90 (1982) 153–162.
- [29] K. Kimura, Sex differences of the hip bone among several Japanese populations, *Okajima's Folia Anat. Jpn.* 58 (1982) 266–273.
- [30] S. Chao, H. Xi, Observation on the Chinese scapulae, *Acta Anthropol. Sinica* [Chinese with English abstract] 5 (1986) 372–376.
- [31] G. Ren, The measurements, correlation and sexual diagnosis of Chinese atlas, *Acta Anthropol. Sinica* [Chinese with English abstract] 5 (1986) 138–142.
- [32] G. Ren, Sexual diagnosis of scapula by discriminant function analysis, *Acta Anthropol. Sinica* [Chinese with English abstract] 6 (1987) 144–146.
- [33] X. Wu, X. Shao, W. Heng, Sex differences and sex determination of the innominate bone of modern Han nationality, *Acta Anthropol. Sinica* [Chinese with English abstract] 1 (1982) 118–131.
- [34] J. Zheng, Anthropological research of tibia in modern Chinese, *Acta Anthropol. Sinica* [Chinese with English abstract] 6 (1987) 19–27.
- [35] T. Zheng, T. Pang, Determination of sex from the tibia by the stepwise discriminatory analysis, *Acta Anthropol. Sinica* [Chinese with English abstract] 7 (1988) 154–159.
- [36] L. Wu, M. Yang, F. Tai, Sex discriminant analysis of long bones of lower limb, *Acta Anthropol. Sinica* [Chinese with English abstract] 8 (1989) 147–154.

- [37] L. Wu, Sex discriminant analysis of long bones of upper limb, *Acta Anthropol. Sinica* (Chinese with English abstract) 8 (1989) 231–239.
- [38] L. Wu, Sex determination of Chinese femur by discriminant function, *J. Forensic Sci.* 34 (1989) 1222–1227.
- [39] M.Y. İřcan, S. Ding, Sexual dimorphism in the Chinese femur, *Forensic Sci. Int.* 74 (1995) 79–87.
- [40] S. Sun, Y. Qu, The measurements and sexual diagnosis of the greater sciatic notch in Chinese, *Acta Anthropol. Sinica* [Chinese with English abstract] 5 (1986) 368–371.
- [41] Q. Du, Measurements of the patellas of Chinese unearthed from the Changchun area, *Acta Anthropol. Sinica* [Chinese with English abstract] 3 (1984) 114–117.
- [42] C. Tan, Some characteristics of the Chinese femur, *Singapore Med. J.* 14 (1973) 505–510.
- [43] R.B. Pickering, Population differences in the calcaneus as determined by discriminant function analysis, in: K.J. Reichs (Ed.), *Forensic Osteology*. Charles C. Thomas, Springfield, IL, 1986, pp. 160–170.
- [44] C.A. King. Osteometric assessment of 20th century skeletons from Thailand and Hong Kong, MA Thesis, Boca Raton. Florida Atlantic University, 1997.
- [45] C.A. King, M.Y. İřcan, S.R. Loth, Metric and comparative analysis of sexual dimorphism in the Thai femur, *J. Forensic Sci.* 43 (1998) 954–958.
- [46] D.L. France, Sexual dimorphism in the human humerus, Ph.D. Dissertation, Boulder, University of Colorado, 1983.
- [47] J. Ditttrick, J. Suchey, Sex determination of prehistoric central California skeletal remains using discriminant analysis of the femur and humerus, *Am. J. Phys. Anthropol.* 70 (1986) 3–9.
- [48] R. Martin, K. Saller. *Lehrbuch der Anthropologie*, vol. 3. Gustav Stuttgart, Fisher, 1957.
- [49] G. Bräuer, Osteometrie, in: R. Knußmann, (Ed.), *Anthropologie: Handbuch der Vergleichenden Biologie des Menschen*, Ban 1, Wesen und Methoden der Anthropologie, Teil 1, Wissenschaftstheorie, Geschichte, Morphologische Methoden, Gustav Fischer Verlag, Stuttgart, 1988, pp. 160–232.
- [50] SPSS, *SPSS-X User's Guide*, Chicago, SPSS Inc., 1988.
- [51] L. St. Hoyme, M.Y. İřcan, Determination of sex and race: accuracy and assumptions, in: M.Y. İřcan, K.A. Kennedy (Eds.), *Reconstruction of Life from the Skeleton*, Wiley-Liss, New York, 1989, pp. 53–94.
- [52] C.A. King, M.Y. İřcan, S.R. Loth, Metric analysis of sexual dimorphism in the Thai tibia, *Am. J. Phys. Anthropol. Suppl.* 26 (1998) 138.
- [53] T.K. Black III, A new method for assessing the sex of fragmentary skeletal remains: femoral shaft circumference, *Am. J. Phys. Anthropol.* 48 (1978) 227–232.
- [54] R. DiBennardo, J.V. Taylor, Sex assessment of the femur: a test of a new method, *Am. J. Phys. Anthropol.* 50 (1979) 635–638.
- [55] M.Y. İřcan, P. Miller-Shaivitz, Determination of sex from the tibia, *Am. J. Phys. Anthropol.* 64 (1984) 53–57.
- [56] M.Y. İřcan, P. Miller-Shaivitz, Determination of sex from the femur in blacks and whites, *Coll. Antropol.* 8 (1984) 169–175.
- [57] C. Ruff, Sexual dimorphism in human lower limb bone structure: Relationship to subsistence strategy and sexual division of labor, *J. Hum. Evol.* 16 (1987) 391–416.
- [58] J. Gray, L. Wolfe, Height and sexual dimorphism of stature among human societies, *Am. J. Phys. Anthropol.* 53 (1980) 441–456.
- [59] R. DiBennardo, J.V. Taylor, Classification and misclassification in sexing the Black femur by discriminant function analysis, *Am. J. Phys. Anthropol.* 58 (1982) 145–151.
- [60] M. Steyn, M.Y. İřcan, Sex determination from the femur and tibia in South African whites, *Forensic Sci. Int.* 90 (1997) 111–119.