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Sex Determination Using the Femur in an Ancient Japanese Population

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ABSTRACT

Determination of sex from the femur measurements has been attempted in several populations and various studies have demonstrated the importance of population specific standards in the metric assessment of sex. The present study attempts to establish metric standards for sex determination by using femur measurements for ancient Japanese populations. Osteometric data were obtained from 151 adult skeletal remains from Jomon period, Yoshigo human skeletal collection. Eight femur measurements were taken and the data were analyzed by discriminant analysis using SPSS version 10.0. For the univariate discriminant function derived, precision of sex determination was 93% with the condyle breadth. Prediction values showed that sex differentiation could be done by femur measurements with reliability between 66.9 and 100%, with values for males higher than for females. It is suggested that discriminant formulas developed by femur measurements in this study, can be used for sex determination accurately on fragmentary skeletal remains in ancient Japanese populations.

***Key words**: femur, sex determination, Yoshigo, Late Jomon, Japan*

Introduction

Assessment of sex from the human skeleton is particularly important both in forensic sciences and in studies of past populations. The determination of sexual dimorphism from osteological material depends on variation in body size and muscularity, and on the childbearing capability in females. In general, the pelvis and skull exhibit prominent sexually dimorphic characters that predict sex with high accuracy[1,2]. In cases where pelvis and skull are not found, it is crucial to get as much information as possible from the other skeletal components. Long bones are especially useful because of the ease of defining measurements and often better preserved[3]. It is also important to develop different equations for use where fragmented human remains are pronounced[4]. From this starting point, the humerus and femur bones are the most important bones. The factors that makes the femur different in male and female are as follows; the axial skeletal weight of the male is relatively and absolutely larger than that of the female and the most of this weight is borne directly by the femur in transmission of the body weight; and obvious modification of the female pelvis with respect to its specialized function in reproduction[2].

Some of the powerful methods of sex determination from skeletal element are based upon the application of statistical analysis to osteological material. Discriminant function analysis is one of the sophisticated mathematical approaches. Long bones are especially favorable for metric analysis. In this regard the femur bone has been studied most extensively. Methods of sex determination by discriminant analysis from the adult femur have been described in several populations by many authors[2,4,5–20]. Each discriminant function formula described has reliability and accuracy. Most of these studies accurately assessed the sex of a skeleton in 80% of the cases.

There have been many studies dealing with sex determination from postcranial skeletons of the Japanese populations. Hanihara studied sexual diagnosis of Japanese long bones, femur and tibia, by means of discriminant function[21]. Nakahashi and Nagai[22], Tagaya[23], İşcan, Yoshino and Kato[24], İşcan et al.[25] and Sakaue[3] studied sex determination from various bones in both recent and prehistoric Japanese populations.

Population specific studies so far conducted for assessment of sex from various parts of the skeleton have

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reiterated the fact that metric standards must be developed for each population because of the size differences between groups[2]. Therefore, the objective of the present study is to conduct discriminant formulae in sex determination by using the femur measurements and establish metric standards for ancient Japanese skeletons.

Material and Methods

Yoshigo shell mound inhabitants were settled there B.C. 14th – 4th century (Late Jomon period) and skeletal remains of 307 individuals were excavated by Kiyono in 1922–1923 in Aichi prefecture, Japan. Yoshigo skeletal sample is the one of the best largest and preserved collections from the Jomon series[26]. In this study, only 151 complete adult skeletons (76 males and 75 females) which has femur and the preservation conditions were quite good were used. All skeletal materials were housed at the Laboratory of Physical Anthropology, Kyoto University, Japan. Due to the good preservation conditions sex determination for each skeleton was based primarily on pelvic and skull morphology[27,28]. Due to preservation conditions, all of the femur measurements can be taken from all of the skeletons, subjected in this study.

The skeletons were selected only adult skeletons with closed epiphyses had been investigated. 8 femoral measurements were taken using standard methods from the left femur[27,28]. The following measurements were taken:

- *Maximum femur length*: Straight distance between the most proximal point of the head and the most distal point of the medial condyle.
- *Trochanter length*: Maximum distance between the greater trochanter and the plane of the two condyles.
- *Transverse diameter*: Distance between the medial and lateral surfaces, perpendicular to long axis of the bone, at midpoint of morphological length.
- *Maximal anteroposterior diameter*: Distance between the anterior and posterior surfaces, perpendicular to long axis of the bone, at midpoint of morphological length.
- *Perimeter*: Circumference in the middle of the shaft.
- *Subtrochanteric transverse diameter*: Distance between the medial and lateral surfaces, at right angle to the long axis of the femur, immediately below the lesser trochanter.
- *Subtrochanteric anteroposterior diameter*: Distance between the anterior and posterior surfaces, in the sagittal plane at a right angle to the long axis of the femur, immediately below the lesser trochanter and avoiding the gluteal tuberosity.
- *Condyle breadth*: Distance between the most projected points on the epicondyles.

The length dimension was taken with an osteometric board, the circumference with a millimetric tape and the other diameters with a sliding caliper.

All statistical computing was carried out using the Statistical Package for the Social Sciences (SPSS) version 10.0. Standard descriptive statistics were calculated, t-test and stepwise analysis were applied. All variables (one by one and in combination) were subjected to discriminant analysis for sex determination. Discriminant analysis is used to classify cases into the values of a categorical dependent. The procedure generates a discriminant function based on linear combinations of the predictor variables that provide the best discrimination between the groups[29]. The most common application of Discriminant function analysis is to include many measures in the study, in order to determine the ones that discriminate between groups.

Results

Table 1 presents the number of individuals, the means and standard deviations of the measurements by sexes and the results of the student t-test for the equality of means. The t-test results showed that all measurements were significantly greater (P<0.001) in males than in females. This state repeats the fact that the average male skeleton is longer, more muscular and heavier than the average female.

TABLE 1
MEANS, STANDARD DEVIATIONS AND UNIVARIATE STATISTICS OF THE FEMUR

Variables (mm)	Male			Female			T value*
	N	X	SD	N	X	SD	
Maximum femur length	25	416.72	19.49	20	381.95	14.88	6.79
Trochanter length	22	394.09	15.97	18	362.06	12.89	7.02
Transverse diameter	75	25.92	1.50	75	24.51	1.56	5.67
Anteroposterior diameter	75	29.59	2.47	75	25.51	2.09	10.94
Perimeter	75	88.84	5.59	74	79.88	5.10	10.23
Subtrochanteric transverse diameter	72	30.64	1.81	73	29.14	1.91	4.84
Subtrochanteric anteroposterior diameter	72	24.78	1.62	73	22.25	1.84	8.80
Condyle breadth	27	78.22	2.81	16	68.91	3.86	8.43

* $p<0.001$.

TABLE 2
STEPWISE DISCRIMINANT FUNCTION ANALYSIS FOR ALL MEASUREMENTS (IN EVERY STEP THE EXCLUDED VARIABLE IS SHOWN IN ITALIC)

Step	Variables	Wilks' Lambda	F-ratio
0	Maximum femur length	0.373	50.363
	Trochanter length	0.378	49.446
	Transverse diameter	0.609	19.224
	Anteroposterior diameter	0.258	86.111
	Perimeter	0.267	82.435
	Subtrochanteric transverse diameter	0.711	12.192
	Subtrochanteric anteroposterior diameter	0.319	63.996
	Condyle breadth	0.236	96.931
1	Maximum femur length	0.209	3.836
	Trochanter length	0.216	2.690
	Transverse diameter	0.234	0.280
	Anteroposterior diameter	0.193	6.444
	Perimeter	0.208	3.908
	Subtrochanteric transverse diameter	0.231	0.671
	Subtrochanteric anteroposterior diameter	0.217	2.608
2	*Maximum femur length*	0.183	1.603
	Trochanter length	0.186	1.142
	Transverse diameter	0.193	0.047
	Perimeter	0.192	0.266
	Subtrochanteric transverse diameter	0.187	0.950
	Subtrochanteric anteroposterior diameter	0.187	0.935

Results of the stepwise discriminant analysis for all femur measurements can be seen in Table 2. Wilks's lambda is a general test statistic used in multivariate tests of mean differences among more than two groups. Several other statistics are special cases of Wilks's lambda. The Wilks' lambda shows the percent contribution of each measurement, and determines the order of variables to enter the function. Lambda ranges between 0 and 1. The values close to 0 indicate that the group means are different, and values close to 1 indicate that the group means are not different. In Table 2, the condyle breadth was the first measurement to be selected by stepwise discriminant analysis.

Results of the discriminant function analysis presented in Table 3 and 4. For each function, the canonical discriminant function coefficients, the sectioning point, the demarking point, the expected accuracy of sex determination is given. In Table 3 functions numbered from 1 to 8 based on single variables are given. The accuracy of sex determination ranged from 66.9 to 93.0%. The condyle breadth measurement was the best single discriminating variable. The sectioning point for assignment of sex was designated as the midpoint between group mean centroids of the male and female. For each discriminant function, when the discriminant score is greater than the sectioning point, it indicates a male individual. The demarking point was designated as the midpoint between male and female arithmetic averages. For each discriminant function, when the discriminant score is smaller than the demarking point, it indicates a female individual. In the discriminant analysis, 93.0% of cases could be grouped correctly using the condyle breadth, 85.0% using the trochanter length, 84.4% using the maximum femur length and 82.6% using the perimeter. In Table 4 functions numbered 9 to 20 indicates the contribution of a variable with the discriminant score related to other variables. With all measurements, 100.0% of cases could be classified correctly. Classification accuracy was generally higher for males than females.

In the discriminant function analysis, dimension should be multiplied by its coefficient and added together along with the constant. For example, if the condyle breadth is measured 73 mm, discriminant function 8 can be applied as follows:

Discriminant function score for condyle breadth (y) = (CB × 0.309) + (–23.130)

$$y = (0.309 \times 73) - 23.130 = -0.573$$

where y – discriminant function score, CB – condyle breadth, constant: –23.130.

This score is smaller than the sectioning point (–0.3685); it indicates that the femur was pertaining to a female. This classification has an anticipated accuracy of 93.0%.

The present study confirms that sexual dimorphism is better reflected in condyle breadth dimension than in femur lengths.

Discussion

Population specific studies have an important role in osteological data analysis. As the discriminant function analysis is a unique mathematical approach, discriminant analysis in sex determination using femur metrical data has been often discussed in the literature. In addition, Yoshigo skeletal collection is one of the largest and best preserved collections from the Jomon series[26] which achieves accurate population specific equation derivation. The present study has confirmed that for sex determination the measurements of the femur display higher classification accuracy.

Results of the prediction values showed that sex differentiation could be done by femur measurements with accuracy between 66.9 and 100%, with male accuracies slightly higher than the females. Many reports from the past studies are consistent with this conclusion. The discriminant analysis study of Purkait and Chandra from India reported that single measurements could assign sex with 71 to 93.5% accuracy[2]. Taylor and DiBennardo tested stepwise multiple discriminant function analysis

TABLE 3
DISCRIMINANT FUNCTIONS ANALYSIS RESULTS (UNIVARIATE)

Function number	1	2	3	4	5	6	7	8
Parameters used	1	1	1	1	1	1	1	1
Maximum femur length	0.057							
Trochanter length		0.068						
Transverse diameter			0.655					
Anteroposterior diameter				0.437				
Perimeter					0.187			
Subtrochanteric transverse diameter						0.537		
Subtrochanteric anteroposterior diameter							0.577	
Condyle breadth								0.309
Constant	–22.797	–25.883	–16.508	–12.046	–15.777	–16.050	–13.566	–23.130
Sectioning point	–0.1095	–0.1090	0	0	–0.0055	0.0025	0.0050	–0.3685
Demarking point	Female <401.27< Male	Female <379.68< Male	Female <25.22< Male	Female <27.55< Male	Female <84.39< Male	Female <29.88< Male	Female <23.51< Male	Female <74.76< Male
Accuracy (%)	84.4	85.0	68.0	80.7	82.6	66.9	77.9	93.0
Correct classify (average)	38/45	34/40	102/150	121/150	123/149	97/145	113/145	40/43

TABLE 4
DISCRIMINANT FUNCTIONS ANALYSIS RESULTS (MULTIVARIATE)

Function number	9	10	11	12	13	14	15	16	17	18	19	20
Parameters used	2	2	2	3	3	3	3	4	6	6	7	8
Maximum femur length					0.024			0.017	0.028		0.014	0.026
Trochanter length								0.012	–0.011			–0.011
Transverse diameter			0.127	0.022		0.104				–0.050	–0.112	–0.002
Anteroposterior diameter	0.163		0.401	0.336		0.153			0.184	0.163	0.258	–0.209
Perimeter		0.074		0.051	0.107			0.192	0.030	0.015	0.016	0.019
Subtrochanteric transverse diameter							0.127	–0.122		0.160	0.085	0.057
Subtrochanteric anteroposterior diameter							0.070		0.139	–0.041	0.163	0.130
Condyle breadth	0.230	0.225			0.160	0.213	0.251		0.159	0.200	0.127	0.159
Constant	–21.745	–23.146	–14.249	–14.095	–30.413	–22.899	–24.220	–23.628	–29.411	–23.381	–26.919	–29.812
Sectioning point	–0.3855	–0.3835	0	–0.0065	–0.1745	–0.3890	–0.3490	–0.1490	–0.1310	–0.3660	–0.1900	–0.1315
Accuracy (%)	95.3	95.3	82.0	82.6	100.0	95.3	97.6	95.0	100.0	95.2	100.0	100.0
Correct classify (average)	41/43	41/43	123/150	123/149	33/33	41/43	41/42	38/40	32/32	40/42	33/33	32/32

for sex assessment on femurs of White North Americans with 82% of accuracy[7]. Studies conducted on modern Japanese skeletons also showed that in Sakaue's study from a total 47 variables of arm bones (humerus, radius and ulna) and leg bones (femur and tibia) sex determination performed with 91% accuracy[3]. Also Hanihara reported that the study results on 88 modern Japanese skeletons' femur measurements gave the probability of misclassification with 3.84%[21].

Wu tested sex determination on Chinese femurs using 17 measurements and a total of 22 discriminant functions composed of various combinations of variables that could assign the correct sex with 82.3 to 87.2%[10]. In addition Wrobel, Danforth and Armstrong developed discriminant functions using long bone robusticty measurements of prehistoric skeletal populations from a Maya site in Belize with accuracy between 77.5 and 98.6%[16].

The bone prominences are the areas where a number of muscles make their insertions and are subjected to more pull than at the point of origin. Articular surfaces of the bone receive a portion of the force being applied across them and will react to such forces[2,30]. This was also the case for the present study. The present findings support previous studies indicating that linear dimensions in femur are less discriminating than perimeter and condyle breadth dimensions. The study of Tranco et al. on femurs from a Spanish population showed that the resulting percentages of correspondence varied between 84 and 97% when each variable was considered independently, whereas a 99% was accuracy obtained with two measurements of the epiphyses combined[4]. King, İşcan and Loth investigated to determine sex from six standard femur measurements using discriminant analysis in Thai skeletons. Results indicated that maximum head diameter and bicondyle breadth are the optimal combination for sex diagnosis and resulted in 94.2% correct classification. Direct analysis revealed bicondyle breadth as the best single dimension (93.3%). Results of the cross-test analysis of the Thai femurs also demonstrated that populations differ from each other in size and proportions and these differences can affect the metric assessment of sex[13]. Steyn and İşcan reported that for South African white population within six femur measurements distal breadths provides the best discrimination between sexes, and according to the discriminant formulae, average accuracies ranged from 86% to 91%[12]. Mall et al. also tested sexual dimorphism by discriminant analysis from femur measurements in contemporary German population. The discriminant analysis results showed that 67.7% of cases could be grouped correctly with the single maximum length measurement, 72.4% with the maximum midshaft diameter, 81.4% with the condyle width and 91.7% with all measurements combined[14].

According to Sakaue, sexual dimorphism tended to be greatest in the breadth diameters of the elbow and knee joints. It is suggested that the bicondyle breadth was useful in sexual diagnosis of the femur, yielding 91% accuracy[3]. Dittrick and Suchey studied a large sample of Central California prehistoric skeletal remains and analyzed sexual dimorphism in the femur and humerus. They suggested that measurements taken at the midshaft and ends of long bone have greater predictive power than most claims for either long bone or cranial sex determination[9]. İşcan and Shihai studied sexual dimorphism from six femur variables in ancient Chinese skeletal populations. Emphasize that three dimensions were selected by the stepwise analysis in the following order: distal epiphysis breadth, maximum length, and anteroposterior diameter of the midshaft. In this study direct analysis revealed that distal epiphysis breadth provided better separation alone (94.9%)[11]. The present study also confirms that in the univariate analysis, the condyle breadth was the best discriminant factor, resulting in 93% level of accuracy for Japanese Jomon population.

DiBennardo and Taylor's study on sex determination using North American White's femurs presented that midshaft femur circumference was able to assign sex with a precision of 82%[6]. Black also investigated the femur circumference measurement using skeletons from Libben Site (Ohio) and reported that femur circumference showed 85% accuracy degree and should be an important aid for the sexual identification of poorly preserved and fragmentary skeletal remains[5]. Nakahashi and Nagai studied fragmentary Japanese skeletal remains from medieval and aeneolithic Yayoi periods, and sex determination by 150 discriminant functions based on the 8 variables showed over 90% accuracy from cranium, upper and lower limb bones and pelvis. In that study contrary to the expectations among humerus, tibia and femur circumferences of the recent Japanese, the femoral circumference showed the lowest accuracy 77.8% when used as a single discriminator. However, in the three excavated archaeological populations, Yoshimohama (Medieval), Doigohama (Yayoi) and Kaneokuma (Yayoi) a single measurement of the femoral circumference revealed an accuracy of 90%[22]. Safont, Malgosa and Subira also studied the circumference of long bones from a Late Roman site in Spain and suggested that the arm circumference functions are more useful than those of the leg, probably because male individuals of the population were subject in life to greater mechanical stress than females[15]. Moreover, MacLaughin and Bruce suggested that maximum anteroposterior diameter of the femur shaft as a sex discriminator has advantages over midshaft circumference even when intact femurs are available[8]. In contrast, the results of the present study demonstrated that although perimeter (82.6%) displayed less classification accuracy than condyle breadth (93%), both of them displayed a higher accuracy than anteroposterior diameter (80.7%).

In the univariate analysis, the condyle breadth was the best discriminant factor with a 93% level of accuracy. In the multivariate discriminant analysis with the combination of 8 femur measurements reliability varies 100% (function numbered 20). The high percentages of accuracy achieved in our discriminant analysis are in the agreement with the findings of the other authors[2–4,11–14,16,21]. This study also agrees with prior findings showing that condyle breadth measurement add more to assessments of sex differences than do all length measurements. Present study demonstrated accuracy between 66.9 and 100% using femur measurements for sex discrimination.

In conclusion, it is important to mention that most of the forensic anthropologists agree that differences between the populations necessitate the population specific standard development for sex determination. As Hanihara reported that the discriminant function as a method of sexual diagnosis is more objective and accurate than many other methods heretofore in use[21], this study demonstrates that the usage of discriminant formulas developed by combination of femur measurements can be used to reliably predict the sex of skeletal remains in ancient Japanese populations.

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ODREĐIVANJE SPOLA KORIŠTENJEM FEMURA KOD DREVNE JAPANSKE POPULACIJE

SAŽETAK

Određivanje spola iz mjerenja femura pokušavalo se u nekoliko populacija, različite studije demonstrirale su važnost specifičnih standarda populacije u metričkoj procjeni spola. U ovoj studiji pokušalo se postići metričke standarde za određivanje spola koristeći mjerenja femura drevnih japanskih populacija. Osteometrički podaci dobiveni su iz 151 odraslih koštanih ostataka iz japanskog perioda, Yoshigo kolekcija ljudskih kosti. Uzeto je osam mjerenja femura te su podaci analizirani analizom diskriminante koristeći SPSS verziju 10.0. Izvedeno za univarijantnu diskriminantnu funkciju, točnost određivanja spola iznosila je 93% sa širinom kondila. Predviđene vrijednosti pokazale su da se razlikovanje spolova može postići mjerenjima femura sa točnošću između 66,9 i 100 %, sa vrijednostima višima za muškarce nego za žene. Predloženo je da se formule određivanja, razvijene iz mjerenja femura u ovoj studiji, mogu koristiti za točno određivanje spola na fragmentiranim koštanim ostacima drevnih japanskih populacija.