A Discriminant Function for Sex Determination of Ancient Iraqis Based on Radial Measurements

YO WADA

*Department of Anatomy, Hyogo College of Medicine,
Mukogawa-cho, Nishinomiya-shi, Hyogo 663, Japan*

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Abstract This paper describes the side difference and sexual dimorphism of the radius in the human skeletal remains from the Himrin Basin, Iraq, and presents a discriminant function for sex determination of Iraqis based on radial measurements. One hundred and eight bones were examined for this purpose using a total of 15 height, width, depth, and girth measurements and indices. All the 15 measurements exhibited insignificant side differences of the radius, while 13 of the original 15 measurements revealed significant sex differences of the radius. A discriminant function for sex determination of the radius was obtained using multivariate techniques. Although the function had high theoretical ratio (95.7%) and observed ratio (95.2% of the 63 cases) of correct diagnoses of sex, it could not be put to the final test owing to the insufficient number of samples. We therefore proposed the function that decreased the incorrect diagnosis rate to the minimum (1%) by setting the doubtful region for reserving sex determination.

Key Words: radius, discriminant function, sex determination, Iraqis

INTRODUCTION

Over 500 human skeletal remains were unearthed from the Himrin Basin, Iraq in 1978-80 (Fujii, 1981). They ranged from a set of only one bone for the limb skeleton to a nearly complete set of about 200 bones. Some were of children, while others were of adults. Over half of them were dated to the Islamic period, while the rest ranged from the Parthian to Samarra periods (6000 B.C. to A.D. 300). We identified the sex, age, and history of disease of each human skeletal remain, and reconstructed population characteristics based on the physical traits of the bones. Also, we identified the racial type of each population, and demonstrated stability or alteration of the populations in time.

We previously studied population characteristics based both on the skull and facial skeleton in the Islamic human skeletal remains (Wada, 1986, 1989), and on the skull and limb skeleton in the Jemdet Nasr human skeletal remains (fourth millennium B.C.) (Ikeda *et al.*, 1986). We also compiled individual histories of the diseases of some of both the Jemdet Nasr and Islamic human skeletal remains (Ikeda *et al.*, 1986; Wada *et al.*, 1987a, 1987b). We then embarked on studies to survey

population characteristics based on the limb skeletons. We first attempted to develop procedures for determination of the sex of the limb skeleton without the pelvis and skull.

The sex of human skeletal remains is generally determined by sexual dimorphism of the pelvis and skull. Sex determination based on sexual dimorphism of the limb skeleton alone is very difficult since the limbs have many transitional forms and considerable intermediate variation. It is well-known that, regardless of sex, the limb skeleton has conspicuously masculine characteristics owing to muscle attachments.

The use of discriminant functions based on multiple measurements is considered the best method for sex determination of the limb skeleton since it completely removes subjectivity. Many scholars have by this time presented discriminant functions for sex determination of the limb skeleton (Pons, 1955; Hanihara, 1958; Kimura, 1971; Rother *et al.*, 1977; Iscan and Miller-Schaivitz, 1984; Dittrick and Suchey, 1986). Although they have clearly demonstrated the efficiency of this method, they caution that discriminant functions produced for the limbs of one population are not readily applied to others. They also note that there are racial differences for even the discriminant function itself.

The present study attempted to describe the side difference and sexual dimorphism of the radius in the Islamic human skeletal remains from the Himrin Basin, Iraq, and then to present discriminant functions for sex determination of ancient Iraqis based on radial measurements.

MATERIALS AND METHODS

One hundred and eight adult radii in the Islamic human skeletal remains were used for this study. They were excavated from the Himrin Basin, Iraq by an archaeological expedition from Kokushikan University in 1978-80 (Fujii, 1981). There were 56 samples, comprising 26 males and 30 females. Twenty-five bones from the left side and 26 from the right belonged to males, while 29 from the left side and 28 from the right were from females. A few bones with pathological deformations were previously excluded (Wada *et al.*, 1987a, 1987b).

The sex was determined twice for each sample based on sexual dimorphism of the pelvis, hip bone and skull (Wada, 1986, 1989). We used the following sexual dimorphism characteristics for sex determination of the samples (Ehrich, 1939; Martin and Saller, 1957; El-Najjar and McWilliams, 1978; Brothwell, 1981). The superior apertures and pubic angles were of the pelvis, while the iliac crests and fossae, greater sciatic notches, preauricular grooves, arc compositions drawn both by the auricular surface and greater sciatic notch, and obturator foramina were of the hip bone. In the skull, we used the supraorbital margins, superciliary arches, glabellae, tuberes frontalia et parietalia, external occipital protuberances, nuchal

lines and mastoid processes for sex determination.

A protocol comprising eleven measurements and four indices was established to examine side and sexual differences of the radius (Table 1). The 11 included two for the height of the whole bone, two for the width and girth of the proximal extremity, and one for the width of the distal extremity. The other six were the widths, depths, and girths of both the shaft and midshaft.

The four indices consisted of two for the length-thickness index of the radius representing robusticity/slenderness of the whole bone, and two for the cross-section index of the shaft representing roundness/flatness of the bone. The former were defined as the ratios of the girth of the shaft to the height of the whole bone, while the latter were ratios of the depth to the width of the shaft. All measurements and indices were based on definitions by Martin and Saller (1957).

In univariate techniques, the Fisher test, Student *t*-test, and Welch *t'*-tests were applied to the respective measurements for determining side and sex differences of the bone. We also used multivariate techniques including the Hotelling's T^2 -test to determine sex differences of the bone (Snedecor and Cochran, 1980), and to obtain discriminant functions for sex determination of the bone (Okuno *et al.*, 1981).

A multivariate technique for obtaining the discriminant function is capable of decreasing the incorrect diagnosis rate to less than a certain value by setting a doubtful region for reserving determination (Okuno *et al.*, 1981). The doubtful region corresponds to the overlapped area of the distributions of the discriminant score for the two groups. The sex of samples plotted in the overlapped area, strictly speaking, can not be determined. The doubtful region is computed based on mean values of the discriminant score for the two groups, and a common standard deviation for the two distributions.

Table 1. Eleven measurements and four indices used for examining the side difference and sexual dimorphism of the radius in the human skeletal remains from the Himrin Basin, Iraq

Code	Measurement	Code	Index
1	Maximum length of the radius	3/2	Length-thickness index of the radius
2	Functional length of the radius	5(5)/1	Length-thickness index of the radius
3	Minimum circumference of the shaft	5/4	Cross-section index of the shaft
4	Transverse diameter of the shaft	5a/4a	Cross-section index of the midshaft
4a	Transverse diameter of the midshaft		
4(1)	Breadth of the proximal extremity		
5	Sagittal diameter of the shaft		
5a	Sagittal diameter of the midshaft		
5(3)	Circumference of the head		
5(5)	Circumference of the midshaft		
5(6)	Breadth of the distal extremity		

Terminology and definitions are based on Martin and Saller (1957).

Fig. 1. Two hypothetical distributions of the discriminant score for two groups and the relation between the distributions and the doubtful region. G1 and G2: names of the two groups; MG1 and MG2: mean values for the G1 and G2 groups; *SD*: common standard deviation for the two distributions; CDP: critical discriminant point for the determination; CDPR and CDPL: critical discriminant points for the right and left limits of the doubtful region; *U*: deviate distance from MG1 to CDP; *NU*: deviate distance from MG1 to CDPR for the doubtful region; *P*: probability of mistaking samples from G1 group for those from G2; and the meshed area under G1 that is beyond CDPR: probability of mistaking samples from G1 group for those from G2 after setting the doubtful region.

Figure 1 illustrates two hypothetical distributions of the discriminant score for both groups, the relation between these distributions, and the doubtful region. Assume G1 and G2 in the figure are the names for two groups. MG1 and MG2 denote the mean values for these groups, and *SD* is their common standard deviation. CDP denotes the critical discriminant point for the determination, while CDPL and CDPR express the critical discriminant points for the left and right limits of the doubtful region. *P* denotes the probability of mistaking samples from G1 group for those from G2, while *Q* is the probability of mistaking samples from G2 for those from G1. *U* is the deviate distance from MG1 to CDP. It is standardized by *SD*, and then transformed into the incorrect diagnosis rate *P*. As the probability is expressed as the area under the distribution curve, *P* is the area under G1 that is beyond CDP.

As the common variance for the two distributions is equal to the distance between MG2 and MG1, the common standard deviation *SD* is given by the square root of the distance. The critical discriminant point CDP is given by the equation $(MG1 + MG2)/2$, and is usually zero. The deviate distance *U* for G1 is given by the equation $0 - MG1$, and the product is standardized by *SD* for transforming into

the incorrect diagnosis rate P . When the U standardized by SD is 1.65, the incorrect diagnosis rate P is about 5%. When the U standardized by SD is 2.33, the incorrect diagnosis rate P is about 1%.

When we set the incorrect diagnosis rate for the doubtful region at 1%, the critical discriminant points move from the prime CDP to the new CDPR and to the new CDPL. The doubtful region is determined between CDPL and CDPR. The new deviate distance NU from MG1 to CDPR for G1 results from multiplying a standardized NU of 2.33 by SD . The critical discriminant point CDPR for the right limit results from adding NU to MG1, while the critical discriminant point CDPL for the left limit is given by subtracting NU from MG2. An incorrect diagnosis rate of 1% is the area under G1 that is beyond CDPR.

Five absolute measurements were used for obtaining discriminant functions for sex determination of the radius. They included the maximum length of the radius, minimum circumference of the shaft, transverse and sagittal diameters of the shaft, and breadth of the distal extremity. We chose these measurements since they precisely represented the morphology of the whole bone and permitted the maximum use of the samples.

RESULTS AND DISCUSSION

Side difference and sexual dimorphism of the radius

Fifty-one males and 57 females were used separately for examining side differences of the radius. The former contained 25 from the left side and 26 from the right, while the latter included 29 from the left side and 28 from the right. A set of basic statistics of the 15 radial measurements and indices is shown in Table 2 for males and in Table 3 for females, and the side difference and sexual dimorphism of the radius are shown in Table 4.

In males, 13 measurements and indices of the right bones were larger than those of the left. The two exceptions were the functional length of the radius and the cross-section index of the midshaft. However, no measurements and indices of the radius exhibited significant side differences.

In females, 12 measurements and indices of the right bones were larger than those of the left. The three exceptions were the transverse diameter of the shaft, breadth of the distal extremity, and length-thickness index of the radius. However, no measurements and indices of the radius exhibited significant side differences.

Although the right radii tended to be larger than the left, no measurements of the radius exhibited significant side differences. On the basis of these results, the radii from both sides were pooled to increase the usable samples. As a result, 108 pooled-radii comprising 51 males and 57 females were used to examine sex differences.

Thirteen measurements and indices of the pooled male radii were larger than those for the female, as shown in the Table 4. The two exceptions were the cross-section

Table 2. Basic statistics for the male radii

Code	Measurement	Left side			Right side			Side-pooled		
		N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.
1	Maximum length of the radius	14	245.07	8.79	14	247.07	9.26	28	246.07	8.92
2	Functional length of the radius	15	231.47	10.47	16	230.31	10.30	31	230.87	10.23
3	Minimum circumference of the shaft	20	43.40	3.14	22	44.32	2.42	42	43.88	2.79
4	Transverse diameter of the shaft	24	17.33	1.86	24	17.79	1.47	48	17.56	1.68
4a	Transverse diameter of the midshaft	13	15.92	1.61	14	16.79	1.19	27	16.37	1.45
4(1)	Breadth of the proximal extremity	16	22.13	0.96	16	22.63	1.03	32	22.38	1.01
5	Sagittal diameter of the shaft	23	12.43	0.99	24	12.96	1.00	47	12.70	1.02
5a	Sagittal diameter of the midshaft	13	12.54	0.97	14	12.71	0.91	27	12.63	0.93
5(3)	Circumference of the head	11	72.27	2.76	12	74.50	2.65	23	73.43	2.87
5(5)	Circumference of the midshaft	12	45.17	3.07	14	46.57	2.28	26	45.92	2.71
5(6)	Breadth of the distal extremity	20	33.05	1.70	16	33.56	1.67	36	33.28	1.68
3/2	Length-thickness index of the radius	14	18.73	1.30	16	19.23	1.03	30	19.00	1.17
5(5)/1	Length-thickness index of the radius	12	18.37	1.25	14	18.87	1.06	26	18.64	1.15
5/4	Cross-section index of the shaft	23	72.12	6.06	24	73.10	5.92	47	72.62	5.94
5a/4a	Cross-section index of the midshaft	13	79.03	4.82	14	76.01	6.69	27	77.46	5.95

Twenty-five of the male radii were from the left side and 26 from the right.

indices of the shaft and midshaft. Thirteen of the original 15 measurements and indices exhibited significant sex differences.

A discriminant function for sex determination of the radius

Sixty-three pooled radii of the original 108 were used for obtaining a discriminant function for sex determination of the radius. They comprised 27 males and 36 females. They had a complete set of the 5 measurements: maximum length of the radius, minimum circumference of the shaft, transverse and sagittal diameters of the shaft, and breadth of the distal extremity. Table 5 shows a discriminant function for sex determination of the radius.

The Hotelling's T^2 -test based on the 5 measurements of 63 bones exhibited significant sex differences ($F = 34.28$; $d.f. = 5, 57$). The two theoretical distributions of the discriminant score for both males and females show means of -5.945 for females and $+5.945$ for males, a common standard deviation of 3.448 for the two distributions, and a critical discriminant point of 0.0 for the sex determination. As the distribution for females had a deviate distance of -1.724 standardized by SD , the theoretical ratio of incorrect diagnoses of sex was estimated at 4.3%.

Table 3. Basic statistics for the female radii

Code	Measurement	Left side			Right side			Side-pooled		
		N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.
1	Maximum length of the radius	19	222.84	9.79	24	225.21	11.03	43	224.16	10.44
2	Functional length of the radius	19	208.37	9.21	25	211.40	10.77	44	210.09	10.12
3	Minimum circumference of the shaft	24	35.79	1.96	26	36.08	2.26	50	35.94	2.10
4	Transverse diameter of the shaft	25	15.00	1.41	26	14.96	1.08	51	14.98	1.24
4a	Transverse diameter of the midshaft	18	13.94	1.21	24	13.96	1.00	42	13.95	1.08
4(1)	Breadth of the proximal extremity	21	19.81	1.33	24	19.88	1.15	45	19.84	1.22
5	Sagittal diameter of the shaft	25	10.28	0.74	26	10.69	0.88	51	10.49	0.83
5a	Sagittal diameter of the midshaft	18	10.39	0.70	24	10.58	0.72	42	10.50	0.71
5(3)	Circumference of the head	21	63.86	4.63	24	64.92	4.55	45	64.42	4.57
5(5)	Circumference of the midshaft	18	38.33	2.87	24	38.58	1.82	42	38.48	2.30
5(6)	Breadth of the distal extremity	21	29.48	2.52	24	29.46	1.84	45	29.47	2.16
3/2	Length-thickness index of the radius	15	17.22	0.85	25	17.11	1.08	40	17.15	0.99
5(5)/1	Length-thickness index of the radius	17	17.16	1.22	24	17.16	0.96	41	17.16	1.06
5/4	Cross-section index of the shaft	25	68.99	7.05	26	71.81	8.10	51	70.43	7.66
5a/4a	Cross-section index of the midshaft	18	74.79	5.52	24	76.15	7.03	42	75.57	6.39

Twenty-nine of the female radii were from the left side and 28 from the right.

Table 4. Side difference and sexual dimorphism of the radius

Code	Measurement	Side difference		Sex difference
		Males	Females	
1	Maximum length of the radius	$t = 0.59$	$t = 0.73$	$t = 9.14 (P<0.001)$
2	Functional length of the radius	$t = 0.31$	$t = 0.98$	$t = 8.72 (P<0.001)$
3	Minimum circumference of the shaft	$t = 1.07$	$t = 0.48$	$t = 15.55 (P<0.001)$
4	Transverse diameter of the shaft	$t = 0.95$	$t = 0.11$	$t = 8.74 (P<0.001)$
4a	Transverse diameter of the midshaft	$t = 1.61$	$t = 0.06$	$t = 7.94 (P<0.001)$
4(1)	Breadth of the proximal extremity	$t = 1.43$	$t = 0.19$	$t = 9.64 (P<0.001)$
5	Sagittal diameter of the shaft	$t = 1.82$	$t = 1.80$	$t = 11.78 (P<0.001)$
5a	Sagittal diameter of the midshaft	$t = 0.47$	$t = 0.86$	$t = 10.81 (P<0.001)$
5(3)	Circumference of the head	$t = 1.98$	$t = 0.77$	$t' = 9.94 (P<0.001)$
5(5)	Circumference of the midshaft	$t = 1.33$	$t = 0.35$	$t = 12.10 (P<0.001)$
5(6)	Breadth of the distal extremity	$t = 0.90$	$t = 0.03$	$t = 8.68 (P<0.001)$
3/2	Length-thickness index of the radius	$t = 1.17$	$t = 0.34$	$t = 7.16 (P<0.001)$
5(5)/1	Length-thickness index of the radius	$t = 1.11$	$t = 0.00$	$t = 5.38 (P<0.001)$
5/4	Cross-section index of the shaft	$t = 0.56$	$t = 1.32$	$t = 1.57$
5a/4a	Cross-section index of the midshaft	$t = 1.33$	$t = 0.68$	$t = 1.23$

Univariate statistics for the sexual dimorphism were based on the basic statistics of the side-pooled radii. The t value was given by the Student t -test, and the t' by the Welch t' -test.

Table 5. A discriminant function for sex determination of the radius with the doubtful region for decreasing the incorrect diagnosis rate to 1%

Code	Measurement	Coefficient
1	Maximum length of the radius	0.0197
3	Minimum circumference of the shaft	0.8371
4	Transverse diameter of the shaft	-0.1741
5	Sagittal diameter of the shaft	1.5510
5(6)	Breadth of the distal extremity	0.4958
	constants	-68.3988
Mean of the discriminant score for males:		+5.9451
Mean of the discriminant score for females:		-5.9451
Positive limit of the doubtful region:		+2.089
Negative limit of the doubtful region:		-2.089

When the radii obtained discriminant scores greater than the critical value (+2.089), they were classified as being from males. Discriminant scores less than the critical value (-2.089) indicate females.

The basic statistics of the observed discriminant score for females showed a mean of -5.945, maximum of +0.39, minimum of -13.29 and standard deviation of 3.22, while the basic statistics for males had a mean of +5.945, maximum of +11.85, minimum of -3.21 and standard deviation of 3.73. In females, the number of correct cases was 35 (97.2%), with the remaining one (2.8%) being incorrect. On the other hand, 25 males (92.6%) were correct, with the remaining two (7.4%) being incorrect. The observed ratio of incorrect diagnoses of sex was estimated at 4.8% for the 63 cases.

Any discriminant function for sex determination of the limb skeleton should be tested by applying it to independently collected samples, to side-separated samples, and larger numbers of samples. However, this discriminant function was obtained based on all the usable samples.

A multivariate technique for obtaining the discriminant function can decrease the incorrect diagnosis rate to less than a certain value by setting a doubtful region for reserving determination (Okuno *et al.*, 1981). We feel this discriminant function would be more useful if the incorrect diagnosis rate was decreased by setting the doubtful region.

As mentioned under methods, the doubtful region is obtained based on the mean values of the discriminant score for the two groups, the common standard deviation for the two distributions, and the rate for incorrect diagnosis. We have already obtained a mean of -5.945 for females, a mean of +5.945 for males, and a common standard deviation of 3.448 for the two distributions.

The problem is how to set the percentage rate for incorrect diagnosis. Although setting the incorrect diagnosis rate at zero is ideal, a more reasonable choice is 1%. Setting the incorrect diagnosis rate at 1% made necessary a standardized new deviate

distance of 2.33. This resulted a new deviate distance of 8.034 obtained from multiplying 2.33 by a common standard deviation of 3.448. A critical discriminant point of 2.089 for the right limit of the doubtful region resulted from adding 8.034 and -5.945 , while a critical discriminant point of -2.089 for the left limit was given by subtracting 8.034 from 5.945. When a bone obtained a discriminant score greater than $+2.089$, it was classified as being from a male. A discriminant score less than -2.089 indicated a female.

In the discriminant function with the doubtful region for decreasing the incorrect diagnosis rate to 1%, the number of correct cases in females was 31 (86.1%), with the remaining 5 (13.9%) being non-classified cases. Twenty-five males (92.6%) were correct, and one (3.7%) was incorrect, with the remaining one (3.7%) being non-classified. The number of incorrect cases, at least, decreased from three (4.8%) of the 63 cases to one (1.6%), compared with the function without the doubtful region. This implies that the discriminant function could decrease the incorrect diagnosis rate to the minimum by setting the doubtful region for reserving sex determination.

Although the discriminant function for sex determination of the radius had a high theoretical ratio (95.7%) and a high observed ratio (95.2% of the 63 cases) of correct diagnoses of sex, it could not be put to the final test owing to the insufficient number of samples. We therefore proposed the function that decreased the incorrect diagnosis rate to 1% by setting the doubtful region for reserving the sex determination. It is well-known that discriminant functions produced for sex determination of the limb skeleton of one population are difficult to apply to others. We also know that there are racial differences even in the discriminant function itself (Hanihara, 1958; Kimura, 1971; Iscan and Miller-Schaivitz, 1984). This study was undertaken to develop discriminant functions for the sex determination of Iraqis based on the limb skeletons because no such discriminant functions currently exist for Iraqis or West Asians.

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