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Metric Characters of the Femora and Tibiae from Protohistoric Sites in Eastern Japan

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Abstract Maximum length and shaft diameters of the femora and tibiae from Protohistoric burial sites in the Kantō district and the southern part of the Tōhoku district were measured. By comparing with the Jōmon and the Modern series from eastern Japan, the Protohistoric series was found to be intermediate between the Jōmon and Modern series in the mid-shaft index of the tibia, but rather unique in that both the femur and tibia of the male are longer and the mid-shaft of the femur is flatter antero-posteriorly, or less pilastric, than the two comparative series. In multiple discriminant analysis, the Protohistoric eastern Japanese series formed a cluster with the Yayoi series from western Japan and the modern Korean series rather than with the Jōmon or the Modern series from eastern Japan.

Human skeletal materials from Protohistoric burial sites have gradually been accumulated in recent years by incessant salvage archaeological excavations that are carried out prior to land development for housing and other purposes. Following the previous article on the minor non-metric variants in the skulls of the Protohistoric population in eastern Japan (YAMAGUCHI, 1985), this paper deals with the lower limb long bones that are usually preserved in relatively better condition than other parts of the postcranial skeleton.

Materials

From the anthropological collections in the National Science Museum, Tokyo and the University Museum, the University of Tokyo, 112 and 87 mature femora and tibiae, excavated at Protohistoric burial sites of mound type (*kofun*) or of cave type (*yokoana* or *ōketsubo*) in the Kantō district and the southern part of the Tōhoku district, were measured. The burials range in date from the Kofun period (the 4th to 7th centuries A.D.) to the Nara period (the 8th century).

Methods

Measurements were taken on the right bones as a general rule. However, when only the left bone was preserved, it was measured as a substitute.

Sex discrimination was made referring to the skull and the innominate bones as long as practicable. However, in not a few cases, anatomical association between different parts of the skeleton had been disturbed as consequences of successive interment of family members in narrow burial space, and each bone had to be discriminated separately. Thus the accuracy of sexing of the present material could not be very high and there remained some bones unsexed.

Definitions of the measurements taken on the femur and tibia are as follows.

The Femur

F1. Maximum length: Maximum distance from the head to the medial condyle measured on an osteometric board. MARTIN's No. 1 (MARTIN & SALLER, 1957).

F2. Sagittal diameter at mid-shaft: Diameter perpendicular to the anterior surface at the level where the linea aspera is the most salient. MARTIN's No. 6.

F3. Transverse diameter at mid-shaft: Diameter parallel to the anterior surface at the same level with F2. MARTIN's No. 7.

F2: F3. Pilastric index.

F4. Maximum subtrochanteric diameter: Maximum transverse diameter of the upper part of the shaft at the level of the strongest bulge of the lateral border or 2–5 cm below the lesser trochanter. Different from MARTIN's No. 9 that is taken in a direction parallel with the femoral neck.

F5. Minimum subtrochanteric diameter: Antero-posterior diameter at the same level with and perpendicular to F4. Different from MARTIN's No. 10.

F5: F4. Subtrochanteric shaft index.

F6. Index of curvature: Ratio of the height to the chord of the curvature of the anterior surface of the shaft. The chord between the proximal and distal ends of the curvature and the distance of the apex of the curvature from the chord were measured with coordinate callipers. Slightly different from MARTIN's No. 27 that is measured with the osteometric board and perigraph.

The Tibia

T1. Maximum length: Projective distance from the spine to the malleolus, with the bone placed on its posterior surface and kept parallel to the long wall of the osteometric board. MARTIN's No. 1a.

T2. Maximum diameter at mid-shaft: Maximum distance from the anterior border to the posterior surface measured approximately at the middle of the bone. MARTIN's No. 8.

T3. Transverse diameter at mid-shaft: Taken at the same level with T2, with the anterior border of the bone placed midway between the two branches of the sliding callipers, in conformity with the definition given by VALLOIS (OLIVIER, 1960). Slightly different from MARTIN's No. 9.

T3: T2. Mid-shaft index.

T1: F1. Tibio-femoral index.

The maximum lengths were taken to the nearest millimeter, and the shaft diameters were read to the nearest millimeter or the half millimeter.

Results

Means and standard deviations of the measurements and indices are given in Table 1. Unfortunately the sample sizes for the tibio-femoral index are too small to draw any significant information from the statistics. For one thing, the chances for both the femur and tibia to be kept intact are limited in the Protohistoric burial sites where the condition is generally unfavorable for bone preservation. Furthermore, it is often difficult to find individual association of bones in jumbled skeletal remains of several family members.

Table 2 gives the coefficients of correlation calculated for four pairs of shaft indices of the femur and tibia. The pilastic index is significantly correlated with the

Table 1. Measurements and indices of the femora and tibiae from Protohistoric sites in eastern Japan.

		Male			Female		
		n	$\bar{x}$	s	n	$\bar{x}$	s
Femur							
1.	Maximum length (M. 1)	35	427.2	21.86	15	396.1	14.35
2.	Sagittal diameter at mid-shaft (M. 6)	73	28.9	2.56	33	24.4	1.56
3.	Transverse diameter at mid-shaft (M. 7)	73	28.4	2.06	33	26.7	1.58
2: 3.	Pilastric index (M6: M7)	73	102.2	10.72	33	91.9	6.46
4.	Maximum subtrochanteric diameter	66	32.5	2.37	33	30.8	1.89
5.	Minimum subtrochanteric diameter	66	25.5	1.95	33	22.0	1.09
5: 4.	Subtrochanteric shaft index	66	78.9	6.55	33	71.6	4.99
6.	Index of curvature	25	3.22	0.78	25	3.19	0.89
Tibia							
1.	Maximum length (M. 1a)	19	349.4	21.82	8	322.4	10.41
2.	Maximum diameter at mid-shaft (M. 8)	55	30.6	2.08	29	26.9	1.42
3.	Transverse diameter at mid-shaft	55	22.6	1.55	29	20.0	1.25
3: 2.	Mid-shaft index	55	73.8	4.98	29	74.7	4.98
T1: F1.	Tibio-femoral index	11	82.1	1.59	7	80.6	1.62

Table 2. Coefficients of correlation of the four shaft indices of the femur and tibia.

		n	r
Pilastic index:	♂	65	0.57**
Subtrochanteric shaft index	♀	33	0.73**
Pilastric index:	♂	24	0.17
Mid-shaft index of tibia	♀	18	0.14
Subtrochanteric shaft index:	♂	24	0.03
Mid-shaft index of tibia	♀	18	0.00
Pilastric index:	♂	25	0.40*
Index of curvature of femoral shaft	♀	25	0.08

*: $P<0.05$, **: $P<0.01$.

subtrochanteric shaft index in both sexes and with the index of curvature in males.

Comparison with the Jōmon and Modern Series

The means and standard deviations of the Protohistoric series are compared with those of the prehistoric Jōmon and Modern series from eastern Japan in Table 3.

The Jōmon data have been compiled from individual measurements of the materials from several shell-mounds in the Kantō and Tōhoku districts (IKEDA and SHIGEHARA, 1975; KUSAMA *et al.*, 1973; OGATA *et al.*, 1971; OGATA *et al.*, 1973; SUZUKI *et al.*, 1957; SUZUKI and HOJO, 1966; YAMAGUCHI, 1983). The statistics of the Modern series are those published by OBA (1950) and SUZUKI (1961) on the skeletal collection of the Kantō Japanese in the Department of Anatomy, the Jikei University School of Medicine, Tokyo, with the exception of the tibio-femoral index that was calculated by the author from the individual measurements published by HIRAI and TABATA (1928) on the materials from the Kinki district.

Both of the femora and tibiae of the Protohistoric series are significantly longer than those of the Modern series in males as well as in females. The Protohistoric femora are also longer than the Jōmon femora in males, but not in females. There is no significant difference between the Protohistoric and Jōmon series in the length of the tibiae.

The most distinctive feature of the Protohistoric lower limb bones is laterally wide flatness of the shaft of the femur. The pilastric index of the Protohistoric femur is not only smaller than that of the Jōmon femur, but is even less than that of the Modern femur in both males and females. The non-pilastric structure of the femora of the Protohistoric people is ascribable to transverse thickness rather than to sagittal thinness of the diaphyses. Twenty-six (35.6 percent) of 73 Protohistoric male femora and 28 (84.8 percent) of 33 female femora are thicker in transverse direction than in sagittal direction, with the pilastric indices less than 100, while such non-pilastric femoral shaft occurs only in 2.4 and 2.9 percent of Jōmon males and females and in 16.7 and 40.0 percent of Modern males and females.

Being positively correlated with the pilastric index, the subtrochanteric shaft index is also significantly smaller in the Protohistoric femora than in the Jōmon and Modern femora in females, but it does not differ significantly between the three series in males. The flatness of the Protohistoric female femora at the subtrochanteric level is also ascribable to larger maximum (transverse) diameter rather than to smaller minimum (sagittal) diameter.

The mid-shaft index of the Protohistoric tibiae is larger than that of the Jōmon tibiae and smaller than that of the Modern tibiae in both males and females. Though there may be some variation among different authors in the way of measuring the mid-shaft diameters of the tibia, the differences are so large and consistent that they seem to demonstrate a steady trend of the decline of platycnemia.

The tibio-femoral index also shows apparent decrease with the times, but none

Table 3. Comparison with the Jōmon and Modern series.

		Male			Female		
		n	$\bar{x}$	s	n	$\bar{x}$	s
Femur							
1. Maximum length	Jōmon	19	415.8*	14.21	12	402.0	12.77
	Protohistoric	35	427.2	21.86	15	396.1	14.35
	Modern	81	412.1**	19.76	88	381.8**	18.08
2. Sagittal diameter at mid-shaft	Jōmon	41	29.6	2.53	35	26.5**	1.54
	Protohistoric	73	28.9	2.56	33	24.4	1.56
	Modern	81	27.6**	2.30	88	24.5	1.71
3. Transverse diameter at mid-shaft	Jōmon	41	25.8**	1.45*	35	24.1**	1.61
	Protohistoric	73	28.4	2.06	33	26.7	1.58
	Modern	81	26.3**	2.25	88	23.0**	1.70
2: 3. Pilastric index	Jōmon	41	115.0**	9.46	35	110.1**	6.63
	Protohistoric	73	102.2	10.72	33	91.9	6.46
	Modern	81	105.4*	8.60	88	107.3**	8.83*
4. Maximum subtrochanteric diameter	Jōmon	14	30.1*	1.19**	18	28.6**	2.00
	Protohistoric	66	32.5	2.37	33	30.8	1.89
	Modern	81	32.1	2.19	88	28.7**	1.86
5. Minimum subtrochanteric diameter	Jōmon	14	24.3*	1.29	18	21.4	0.99
	Protohistoric	66	25.5	1.95	33	22.0	1.09
	Modern	81	24.9	1.82	88	21.9	1.43
5: 4. Subtrochanteric shaft index	Jōmon	14	80.9	5.37	18	75.0*	4.80
	Protohistoric	66	78.9	6.55	33	71.6	4.99
	Modern	81	77.7	6.10	88	77.7**	5.53
Tibia							
1. Maximum length	Jōmon	14	345.7	19.82	11	325.2	16.04
	Protohistoric	19	349.4	21.82	8	322.4	10.41
	Modern	80	325.3**	15.58*	80	302.4**	16.03
2. Maximum diameter at mid-shaft	Jōmon	37	31.0	2.48	33	27.4	1.88
	Protohistoric	55	30.6	2.08	29	26.9	1.42
	Modern	80	28.7**	2.14	80	25.7**	1.94
3. Transverse diameter at mid-shaft	Jōmon	37	21.5**	1.70	33	19.6	1.56
	Protohistoric	55	22.6	1.55	29	20.0	1.25
	Modern	80	22.8	1.70	80	20.3	1.56
3: 2. Mid-shaft index	Jōmon	37	69.4**	4.62	33	71.5*	6.24
	Protohistoric	55	73.8	4.98	29	74.7	4.98
	Modern	80	78.7**	6.52*	80	78.7**	6.76
T1: F1. Tibio-femoral index	Jōmon	8	83.0	2.23	7	81.9	0.94
	Protohistoric	11	82.1	1.59	7	80.6	1.62
	Modern (Kinai)	30	80.3	2.15	20	79.8	2.16

**,*: significantly different from the Protohistoric series at the level of 0.01 or 0.05.

of the differences are statistically significant. A larger sample is needed to ascertain the trend in this character.

Table 4. PENROSE's shape distances based on eight measurements of the femur and tibia.

Distance between:	Male C_z^2	Male (C_z)	Female C_z^2	Female (C_z)
Protohistoric and Jōmon	0.2891	(0.54)	0.7780	(0.88)
Protohistoric and Modern	0.2672	(0.52)	0.6347	(0.80)
Jōmon and Modern	0.7220	(0.85)	0.5363	(0.73)

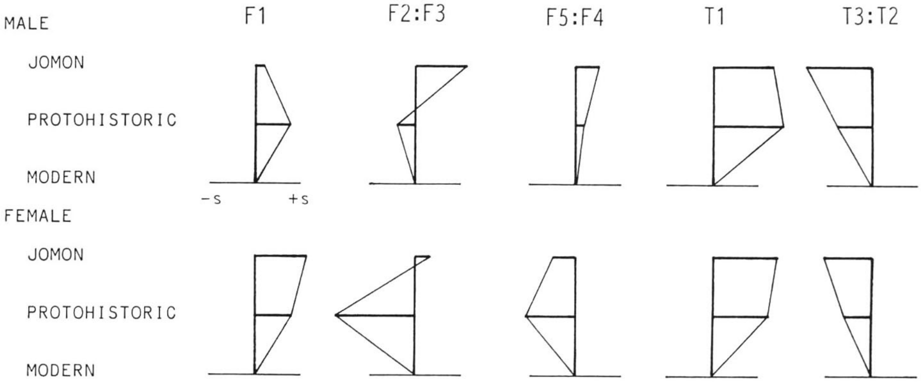

Fig. 1. Deviation diagrams using the Modern series as standard. The vertical and horizontal bottom lines indicate the mean and ±1 S.D. of the standard series.

With regard to sex differences, the Protohistoric femora are characterized by pronounced dimorphism in the maximum length and the pilastric index. The female/male ratio of the mean maximum length of the Protohistoric femora is 0.927. It is close to 0.926 of the Modern femora, but smaller than 0.967 of the Jōmon femora. The ratio of the pilastric index is 0.899 in the Protohistoric series. It is far smaller than 0.957 of the Jōmon series and 1.018 of the Modern series. On the other hand, the tibia shows little variation in sex dimorphism among the three series.

PENROSE's shape distances between the three series computed for the eight measurements are given in Table 4. The distance pattern of male series does not resemble that of female series. In the male, the remotest are the Jōmon and the Modern, and the Protohistoric is placed between and almost equally distant from them, whereas, in the female, the Jōmon and the Modern are relatively close to each other and the Protohistoric is somewhat apart from them with nearly equal distances. There is no tendency for any pair of the series to form a distinct cluster.

Metric characteristics of the Protohistoric femora and tibiae as compared with those of the Jōmon and Modern series are illustrated by deviation diagrams in Fig. 1. The maximum length of the femur in the female, the subtrochanteric shaft index in the male, the maximum length of the tibia in the female, and the mid-shift indices of the tibia in the male and female show unidirectional shift from the Jōmon to the Modern series through the Protohistoric series. However, the Protohistoric series is not in line with the trend from the Jōmon to the Modern series in the maximum length of the femur and tibia of males, the pilastric index of both sexes and the subtrochanteric shaft index of females. In sum, the peculiarities of the Protohistoric lower limb long bones are in the largish size of the male femora and tibiae and the antero-posterior flatness of the femoral shaft that is especially pronounced in female femora.

Discussion

(*1*) *Stature Estimates*

That the femora of the Protohistoric population in the Kantō district were longer in average than those of the Jōmon, Medieval and Early Modern populations from the same district was first disclosed by Hiramoto (1972). Making use of Fujii's formulae (Fujii, 1960) for estimation of stature (S) from maximum length of right femur (F),

$$S(\text{male}) = 2.47F + 549.01 \text{ (mm)}$$
$$S(\text{female}) = 2.24F + 610.43 \text{ (mm)}$$

Hiramoto estimated the average stature of the Protohistoric males and females from the Kantō district at 1631 and 1515 mm respectively. These estimates were obtained from 22 male and 9 female right femora of which average maximum lengths were 437.9 and 403.0 mm. Although Hiramoto's materials overlap those measured by the present author, the present series comprising 35 male and 15 female femora gave slightly lower estimates than Hiramoto's; i.e. 1604 mm for males and 1498 mm for females. The revised estimates are still larger than the estimates of the Jōmon, Medieval, and Early Modern average stature.

Whether this temporary increase of average stature during the Protohistoric period was a sort of non-genetic modification or was a result of genetic influence of immigrants from the Asian Continent who were somewhat taller than the indigenous Jōmon population is no easy question to answer. Many other osteological characters and various archaeological informations should be taken into consideration before drawing a conclusion on this problem.

(*2*) *Pilastric Index*

Another striking feature of the Protohistoric lower limb bones is the antero-posterior flatness of the femoral shaft, as manifested quantitatively in the low averages of the pilastric indices.

It is known that the pilastric index was very low during the *Homo erectus* stage of human evolution, with the exception of the Trinil femur (e.g. Day, 1971). The index values of the *Homo erectus* femora from Locality 1 at Choukoutien, for example, range from 79.4 to 91.2 (Weidenreich, 1941). The pilastric structure developed gradually during the subsequent Neanderthal and Neanderthaloid phase and reached

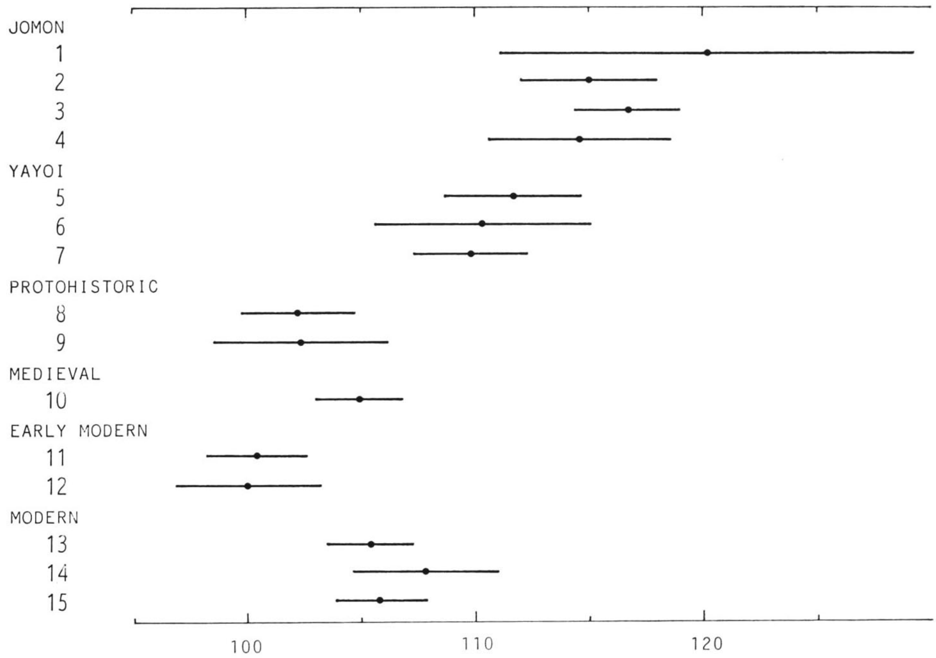

Fig. 2. Comparison of the pilastric index in male series from the Jōmon and subsequent periods. The center dot represents the mean and the horizontal line the 95% confidence interval for the mean. 1, Earliest and Early Jōmon (OGATA, 1981); 2, eastern Japan (Table 3); 3, Yoshiko (ISHISAWA, 1931); 4, Tsukumo (KIYONO and HIRAI, 1928); 5, Ōtomo (MATSUSHITA, 1981); 6, Kanenokuma (NAKAHASHI *et al.*, 1985); 7, Doigahama (ZAITSU, 1956); 8, eastern Japan (present study); 9, western Japan (JO, 1938); 10, Kamakura (KOHARA, 1956); 11, Edo (MORIMOTO *et al.*, 1985); 12, Edo (HIRAMOTO, 1979); 13, Kantō (Table 3); 14, Kinai (HIRAI and TABATA, 1928); 15, Kyūshū (ABE, 1955).

the climax in the Upper Palaeolithic population of late Upper Pleistocene times. To cite a few examples, the pilastric index is as high as 116.4 in the Liukiang femur (WOO, 1959), 112.0–139.5 in the Choukoutien Upper Cave femora (WEIDENREICH, 1941), and 119.6–129.0 in the Cro-Magnon femora (ALEKSEEV, 1978). The right femur of Mikkabi man from central Honshu, dated to the late Upper Pleistocene, is also characterized by a pronounced pilastric structure with index value of 120.8 (SUZUKI, 1962).

The population in the Japanese Archipelago kept on subsisting by hunting, fishing, and collecting during the postglacial Jōmon period (approx. 10000–300 B.C.) and maintained many of archaic morphological characters of the Upper Palaeolithic population, including the salient pilaster of the femur (YAMAGUCHI, 1982).

Average pilastric indices of some representative series of the Jōmon and subsequent periods are given in Fig. 2. The change of the average index with times is not monotonous. The pilastric index declines sharply during the Yayoi period, reaching the bottom in the Protohistoric period to stay there until the Edo (Early Modern) period, and then turns upward in modern times.

RUFF, LARSEN, and HAYES (1984) observed a similar decline of the pilastric structure that occurred in a prehistoric population on the Georgia Coast in North America with the transition from hunting-gathering to agriculture. The fall of the pilastric index during the Yayoi and Protohistoric Kofun periods may also be attributed to changes in physical activities and behaviour caused by introduction of rice cultivation from the Continent in the Yayoi period. However, the rising of the index in the modern Japanese is hard to explain. It might be a matter of sampling bias because the materials of the modern Japanese are from anatomical collections in medical schools.

It has long been known that highly pilastric femora tend to be strongly curved antero-posteriorly in average (e.g. MARTIN, 1928; ISHISAWA, 1931). The present Protohistoric femora also corroborate it the other way, since not only they are non-pilastric but also are curved weakly in average, making a sharp contrast with markedly pilastric and strongly curved femora from the Jōmon period. Although the method of measurement followed by ISHISAWA (1931) might have been slightly different from that in the present study, the average indices of curvature of the femoral shaft, 4.4 and 4.1, obtained by him for 41 male and 45 female right femora from Yoshiko shell-mound, are definitely larger than those of the present Protohistoric male and female femora, 3.2 and 3.2.

In spite of such apparent association between the development of the pilaster and the antero-posterior shaft curvature in intergroup comparisons, results of intragroup correlation analyses are not consistent. In the present series, the coefficient of correlation between the pilastric index and the index of curvature is significant at 0.05 level in the male, but not in the female (Table 2). HIRAI and TABATA (1928) and ARASE (1933) failed to find significant correlation between these two indices in the materials of the modern Japanese and Koreans. Therefore, the variation in the pilastric structure can not simply be related with the degree of curvature of the femoral shaft. The author believes that only a more elaborate investigation based on biomechanical standpoint can throw light on this interesting problem.

(3) *Discriminant Analysis*

In order to learn the position of the Protohistoric series in the morphological distance relationship among various series of different geographical and chronological provenances in East Asia, a multiple discriminant analysis was applied to ten lower limb skeletal series using the following four measurements: maximum length of the femur, sagittal and transverse mid-shaft diameters of the femur, and maximum length of the tibia. Subtrochanteric diameters of the femur and mid-shaft diameters of the tibia were not used because of possible differences in measuring methods followed by different authors. Male means of the four measurements in the ten series and their sources are given in Table 5. The within-group variances and covariances used in

Table 5. Means of four measurements and scores of two discriminant functions of ten lower limb skeletal series from East Asia.

	(n) and Means of Measurements				D. F. Scores	
	MLF	SDF	TDF	MLT	(I)	(II)
Jōmon, eastern Japan (from Table 3)	(19) 415.8	(41) 29.6	(41) 25.8	(14) 345.7	*0.36*	*1.82*
Jōmon, Tsukumo (KIYONO & HIRAI, 1928)	(13) 418.2	(19) 29.3	(19) 25.5	(8) 349.5	*1.73*	*2.42*
Yayoi, Doigahama (ZAITSU, 1956)	(12) 431.5	(56) 28.6	(56) 26.1	(10) 352.5	*3.21*	*0.56*
Yayoi, Kanenokuma (NAKAHASHI *et al.*, 1985)	(11) 438.6	(30) 29.4	(30) 27.7	(11) 345.3	*0.38*	*−3.22*
Protohistoric, eastern Japan (from Table 1)	(35) 427.2	(73) 28.9	(73) 28.4	(19) 349.4	*2.23*	*−1.61*
Early Modern, Edo (MORIMOTO *et al.*, 1985)	(51) 405.7	(85) 26.4	(85) 26.3	(43) 329.3	*−1.32*	*0.43*
Modern, Kantō district (from Table 3)	(81) 412.1	(81) 27.6	(81) 26.3	(80) 325.3	*−3.71*	*−1.22*
Modern, Kyūshū district (ABE, 1955; INABE, 1955)	(62) 405.7	(62) 26.5	(62) 25.2	(64) 328.5	*−1.75*	*1.36*
Modern, Korea (ARASE, 1931, 1933)	(64) 425.2	(64) 27.1	(64) 26.5	(136) 349.6	*3.87*	*0.73*
Neolithic, North China (YEN, 1973)	(13) 461.0	(14) 29.4	(14) 29.1	(14) 374.3	*8.87*	*−3.02*

MLF, MLT = maximum length of femur and tibia; SDF, TDF = sagittal and transverse diameter of femur at mid-shaft.

Table 6. Within-group variance and covariance matrix.

	F1	F2	F3	T1
F1 (Maximum length)	379.18	26.29	11.86	272.55
F2 (Sagittal diameter at mid-shaft)		6.29	1.75	26.79
F3 (Transverse diameter at mid-shaft)			3.06	14.03
T1 (Maximum length)				303.19

the computation were obtained from 107 male femora, comprising 30 modern Japanese (HIRAI and TABATA, 1928), 37 Ainu (KOGANEI, 1893), and 40 Jōmon and Protohistoric femora (KIYONO and HIRAI, 1928; ISHISAWA, 1931; YAMAGUCHI, 1983; and the present series) (Table 6).

Scores on the first two discriminant functions are given in Table 5 and plotted in Fig. 3. A slender cluster is formed by the two Jōmon series from Tsukumo and eastern Japan, the Early Modern series from Edo, and the two Modern series from Kantō and Kyūshū. The Neolithic Northern Chinese series from Hsi-hsia-hou (Xixiahou) is the remotest from the said cluster. The Protohistoric series is situated inbetween and forms another cluster with the two Yayoi series from western Japan and the modern Korean series.

It is unfortunate that human skeletal remains from archaeological sites in Korean Peninsula are still quite limited in number and only the modern skeletal series are

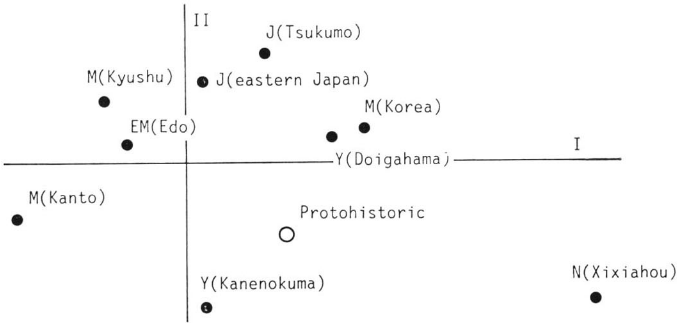

Fig. 3. Location of the ten series on the four-variable discriminant functions I and II (Table 5). J = Jōmon, Y = Yayoi, EM = Early Modern, M = Modern, N = Neolithic.

available as statistically comparable materials from that part of East Asia. Nevertheless, it is quite interesting that the Yayoi and Protohistoric series from Japan are fairly close morphologically to the modern Korean series. A similar resemblance between the modern Korean material and the eastern Japanses Protohistoric material had been observed in the incidence pattern of various non-metric variants in the skull (YAMAGUCHI, 1985). This coincidence is tempting to develop a speculation on the relationship between the Korean and Japanese populations during the Yayoi and the Protohistoric periods, but it will be deferred until accomplishing a similar analysis on craniometric data in the near future.

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