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Which Equations Should be Used to Estimate the Stature of Ancient Japanese Populations?

By

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Abstract In order to choose the most suitable stature estimation equations for Japanese ancient populations, six sets of equations for males and two sets of equations for females were examined for modern Japanese, Kofun people, Yayoi people, Jomon people and modern Koreans. Using the discrepancy between estimated statures based on each of the four different long bones (femur, tibia, humerus and radius) as a criterion, FUJII's equations are the most suitable for modern Japanese, Kofun people and Jomon people for both sexes with the condition that humerus is not to be used for Jomon people. For male migrant type Yayoi people, TROTTER and GLESER's equations for Mongoloids are the most suitable. For female Yayoi people, FUJII's equations are more suitable than PEARSON's equations. Secular changes in body proportion were discussed.

Introduction

There are two problems to consider when estimating the stature of ancient people from their long bone length: which equation should be used and which bone should be used.

The stature of prehistoric people is estimated from long bone length using a regression equation calculated from modern skeletal materials. As the ratio of long bone length to stature can be quite different in different racial groups, it is recommended that the stature be estimated using equations calculated on the same racial group as the subject. To illustrate, STEVENSON (1929) found that the estimated stature of modern North Chinese, based on PEARSON's equations for a French population (PEARSON, 1899), is about 4 cm less than their actual stature, and the estimated stature of French people, obtained from STEVENSON's equations for North Chinese, is about 4 cm greater than their actual stature.

The equations most commonly used to estimate the stature of Japanese prehistoric people are those of PEARSON since KANASEKI and TABATA (1930). To obtain a reliable estimate, the relationship between long bone length and stature in the prehistoric Japanese population must be similar to that in the population from which the equations were calculated. However, minimal attention has been paid to this condition, even though it is unlikely that it has been met. HIRAMOTO (1972) used FUJII's equations (FUJII, 1960) to estimate the stature of prehistoric and historic Japanese populations. They are calculated from Japanese data, and thus seem to be more appropriate for Japanese populations than the equations calculated from Caucasoid or Negroid data. However, FUJII's equations are not as popular as PEARSON's. Also, as Jomon people had relatively longer forearms than modern Japanese (YAMAGUCHI, 1967), it may not be proper to use FUJII's equations to estimate their stature.

Usually the lengths of the femur, tibia, humerus and radius (sometimes fibula and ulna as well), either separately or in combination, are used to estimate the stature. For an ancient population, it is practical to use equations based on only one long bone because the excavated skeletons are not necessarily completely preserved. Many authors have found that the estimation based on the femur or tibia is the most reliable, with the smallest estimation error (PEARSON, 1899; STEVENSON, 1929; and others). When the upper limb bones are preserved but the lower limb bones are not, should information on the subject's stature be ignored completely? If the differences between the estimates based on each of the four long bones are small enough, then sample size can be increased by using whichever of those bones available.

FOLMICOLA (1983) suggested a criterion for deciding which equations should be used for a population. The basic idea is to use equations derived from the population whose long bone length-stature proportion is closest to that of the population in question. To evaluate the similarity in the long bone length-stature proportion, the discrepancy between estimated statures based on each of the four different long bones (femur, tibia, humerus and radius) can be used. Estimated statures based on each of the femur, tibia, humerus and radius should be very close to each other, because they are estimates of the same thing, actual stature. This may not be true for every person because of individual variation in body proportion. However, for a population, mean estimated statures based on each of the four different bones should be very similar if the relationships between the long bone lengths and stature of the population in question are similar to those in the population from which the equations were calculated. Using delta (the average of the differences in the stature estimates obtained from each of the different bones) as a measure of the variability among the four stature estimates, FORMICOLA found that TROTTER and GLESER's equations for Negroids were the most suitable for Italian prehistoric populations (FORMICOLA, 1983).

The purposes of the present paper are to decide the most suitable equations for Japanese prehistoric populations based on the above reasoning, and to decide if it is safe to pool stature estimates for an individual that are based on different bones.

Materials and Methods

1. Measurements

Maximum lengths of the femur, tibia, humerus and radius were measured according to MARTIN und SALLER (1957). When slight damage made it impossible to measure the maximum length, the maximum length was estimated by comparing that bone with a complete bone of about the same length.

All available long bones were measured for each individual. Measurements on right bones were used preferentially for the analyses. When the right bone was not preserved or was damaged, the measurement for the left bone was used.

In PEARSON's and STEVENSON's equations, tibial length without spine (MARTIN No. 1: total length) was used instead of maximum length of tibia (MARTIN No. 1a). In Wang *et al.*'s equations, physiological length of femur (MARTIN No. 2) was used instead of maximum length of femur (MARTIN No. 1). For this study, the total length of tibia and the physiological length of femur were estimated from maximum lengths of the tibia and femur, respectively, using the following regression equations.
Regression equations for the tibia (unit=mm):

male: (total length) $= 0.9803 \times$ (maximum length) $+ 1.1045$

$R^2 = 0.992$ $(N = 50)$;

female: (total length) $= 0.9982 \times$ (maximum length) $- 3.7939$

$R^2 = 0.990$ $(N = 40)$.

Regression equation for the femur (unit=mm):

male: (physiological length) $= 1.0041 \times$ (maximum length) $- 5.4301$

$R^2 = 0.995$ $(N = 51)$.

These regression equations were calculated from the modern Japanese data of HIRAI and TABATA (1928) and SEKI (1931).

2. Skeletal materials

Skeletal materials from the Kofun, Yayoi and Jomon periods belonging to the Department of Anthropology and Prehistory, University Museum, the University of Tokyo; the Department of Anthropology, National Science Museum, Tokyo; and the Kiyono Collection kept in the Department of Physical Anthropology, Faculty of Science, the University of Kyoto, were measured by the present author. Measurements of Kofun and Yayoi materials were also taken by Professor Jiro IKEDA of the Faculty of Liberal Arts and Science, Okayama University of Science. The remaining data were cited from the literature (see Appendices 1, 2 and 3).

Sex was determined on the basis of the morphology of all available skeletal parts for each individual.

(A) Kofun materials

To make the sample as homogeneous as possible, only materials from the eastern part of Japan were used for males. Because of the small sample size, materials from the whole of Honshu were used for females. About 70% of the male samples and about 50% of the female samples were from the Kanto District. Dates for the materials range from the 4th to 9th century. Many of the materials from the Kanto District are from the 6th century or later.

The sample sizes used are given in Table 1.

(B) Yayoi materials

The materials used were of the Northern Kyushu type of NAITO (NAITO, 1984).

Table 1. Kofun materials.

	Males			Females		
	r.	l.	total	r.	l.	total
Femur	56	29	85	50	20	70
Tibia	27	9	36	25	12	37
Humerus	13	12	25	19	6	25
Radius	10	2	12	10	5	15

They were excavated mainly from the Northern part of Kyushu and the Chugoku District, and are considered to be the descendants of the migrants from the Asian Continent who introduced rice cultivation into Japan. The name "migrant type" instead of "Northern Kyushu type" is used in this paper to avoid confusion. Most of the Yayoi data were cited from the literature (Appendix 2). The Yayoi period is from 300 B. C. to 300 A. D.

The sample sizes used are given in Table 2.

Table 2. Yayoi materials.

	Males			Females		
	r.	l.	total	r.	l.	total
Femur	43	6	49	32	4	36
Tibia	42	2	44	31	2	33
Humerus	33	2	35	30	1	31
Radius	28	1	29	24	1	25

(C) Jomon Materials

The Jomon materials used were excavated from three shell mounds, the Yoshiko shell mound in Aichi Prefecture (late to latest Jomon), the Tsukumo shell mound in Okayama Prefecture (late to latest Jomon) and the Ohta shell mound in Hiroshima Prefecture (early to late Jomon). Original measurements by ISHIZAWA (1931) and OHBA (1935 a, 1935 b), KIYONO and HIRAI (1928 a, 1928 b) and IMAMICHI (1934, 1935) were used. The Jomon people were hunter-gatherers living throughout Japan until about 300 B. C.

The sample sizes used are given in Table 3.

Table 3. Jomon materials.

	Males			Females		
	r.	l.	total	r.	l.	total
Femur	40	28	68	34	15	49
Tibia	35	26	61	30	12	42
Humerus	41	33	74	38	13	51
Radius	42	31	73	44	13	57

(D) Modern materials

For comparative purposes, long bone measurements of modern Japanese (MIYAMOTO, 1925; HIRAI and TABATA, 1928) and of modern Japanese who died of tuberculosis (SEKI, 1931; OHBA, 1934) were used. These two series were pooled because the average long bone lengths for each series were not significantly different. Only data from individuals with measurements for all four long bones were used. The number of subjects was 42 for males and 40 for females.

(E) Modern Korean materials

Also for comparative purposes, data on modern Koreans (ARASE, 1931 a, 1931 b; TAKAHASHI, 1932 a, 1932 b) were used. The male samples consist of 64 femora, 136 tibiae, 115 humeri and 111 radii, and the female samples of 13 femora, 9 tibiae, 10 humeri and 10 radii. Only the right bones were used.

3. Estimation equations

The eight sets of equations examined in this study, six sets for males and two for females, are shown in Table 4. Equations based on the fibula and ulna were not used because PEARSON (1899) and STEVENSON (1929) did not use them. Only those equations using the femur, tibia, humerus and radius separately were used, because it is not practical to use equations based on more than one bones for excavated skeleton which is often not well preserved. For females, only the equations of PEARSON (1899) and FUJII (1960) are available.

(A) FUJII's equations (FUJII, 1960)

FUJII's data consist of 165 male and 27 female Japanese cadavers from the dissecting room. FUJII calculated 31 regression and multiple regression equations based on the femur, tibia, fibula, humerus, radius and ulna for both males and females. Equations using physiological lengths and maximum lengths were calculated. In this study, the equations using maximum lengths i.e., FUJII's equation no. 1 for each bone, were used.

In FUJII's equations, a value which was supposed to be close to the individual's living stature obtained from the cadaver was estimated from the length of a dry macerated bone. Different equations were calculated for right and left bones.

(B) PEARSON's equations (PEARSON, 1899)

PEARSON's equations are based on data from 50 male and 50 female cadavers. Ten regression and multiple regression equations using the femur, tibia, humerus and radius were calculated. Total length instead of maximum length is used for the tibia. The equations used in this study are PEARSON's equations a, b, c and d.

As the long bones were measured with dried cartilage attached, before calculating the equations, 7.1 mm, 4.7 mm, 4.1 mm and 2.2 mm were subtracted from the lengths of the femur, tibia, humerus and radius, respectively, to correct for the thickness of the cartilage. In PEARSON's equations the living stature estimated from cadaver length was regressed on the long bone length corrected for cartilage thickness.

Only the right bones were used to derive PEARSON's equations, so when a left bone

Table 4. Estimation equations.

Males

Author	Subjects	Measurement	Equations (unit cm) Right side	Left side
1. FUJII, A. (1960)	Japanese N=165 156.5 cm	Maximum length	S=2.47F+54.901 S=2.47T+73.999 S=2.79H+73.242 S=3.23R+84.296	S=2.50F+53.560 S=2.36T+77.542 S=2.83H+72.908 S=3.30R+83.401
2. PEARSON, K. (1899)	French N=50 165.0 cm	Tibia measured without spine	S=1.880F+81.306 S=2.376T+78.664 S=2.894H+70.641 S=3.271R+85.925	
3. STEVENSON, P. H. (1929)	North Chinese N=48 168.9 cm	Tibia measured without spine	S=2.4378F+61.7207 S=3.0263T+59.2256 S=2.8131H+81.5115 S=3.7384R+80.0276	
4. TROTTER, M. and G. C. GLESER (1958)	Mongoloid heterogeneous group N=92 168.73 cm	Maximum length	S=2.12F+74.03 S=2.42T+80.36 S=2.69H+82.80 S=3.58R+80.71	S=2.18F+71.11 S=2.36T+82.54 S=2.68H+83.27 S=3.51R+83.40
5. TROTTER, M. and G. C. GLESER (1958)	Negroid N=577 173.43 cm	Maximum length	S=2.07F+73.78 S=2.20T+84.90 S=2.88H+75.52 S=3.28R+86.22	S=2.14F+70.19 S=2.18T+85.82 S=2.89H+75.10 S=3.36R+84.63
6. WANG, Y. *et al.* (1979)	Southwestern Chinese N=40 162.55 cm	Femur: physiological length	S=2.52F+54.69 S=2.80T+64.33 S=3.48H+55.54 S=3.58R+78.89	

Females

Author	Subjects	Measurement	Equations (unit cm) Right side	Left side
1. FUJII, A. (1960)	Japanese N=27 146.6 cm	Maximum length	S=2.24F+61.043 S=2.20T+77.871 S=2.38H+81.302 S=3.13R+82.934	S=2.33F+57.841 S=2.34T+73.754 S=2.49H+78.742 S=3.21R+81.931
2. PEARSON, K. (1899)	French N=50 152.3 cm	Tibia measured without spine	S=1.945F+72.844 S=2.352T+74.774 S=2.754H+71.475 S=3.343R+81.224	

must be used, we are instructed to add 4.2 mm to the humerus (5.1 mm for a female subject) and 2.8 mm to the radius (1.9 mm for a female subject). In this study no correction was made for bilateral differences.

(C) STEVENSON's equations (STEVENSON, 1929)

STEVENSON's equations are based on data from 48 male North Chinese. Cadaver length is estimated from the length of dried macerated bone. Ten regression and multiple regression equations were calculated, of which those relating to the femur, tibia, humerus and radius separately were used in this study. Total length instead of maximum length was used for the tibia.

Only the right bones were used in Stevenson's equations, but no correction was made for bilateral differences in this study.

(D) TROTTER and GLESER's equations for Mongoloids (TROTTER and GLESER, 1958)

These equations are based on data from 92 soldiers of oriental origin killed in the Korean war. The subjects are heterogeneous and consist of 23 Japanese, 22 American Indians, 20 Philippinos, 9 Hawaiians, 2 Chinese, 1 Malay and 13 hybrids.

Ten regression and multiple regression equations based on the femur, tibia, fibula, humerus, radius and ulna were calculated. Living stature is estimated from the maximum length of the long bones. The condition of the long bones at measurement varies from wet to dry.

Different equations for the right and left bones were used in this study.

(E) TROTTER and GLESER's equations for Negroids (TROTTER and GLESER, 1958)

The subjects were 577 Negroid soldiers killed in the Korean war, most of them from the United States. The details of the equations are the same as those mentioned above for the Mongoloids.

These equations were included in this study because the relationship between the humerus and radius in Jomon people is closer to that of the modern Negroid than to modern Japanese (YAMAGUCHI, 1967).

(F) WANG *et al.*'s equations (WANG *et al.*, 1979)

Ten regression and multiple regression equations were calculated based on data from 40 male Chinese from southwest China. The condition of the long bones at measurement is unknown.

Physiological length instead of maximum length was used for the femur. Average values of the right and left bone lengths were used to estimate the cadaver length, but in the present study no correction was made for bilateral differences, because it was impossible to calculate the average of the right and left bones for most of the excavated individuals.

4. Methods of analysis

For each population, the mean estimated stature based on each of the femur, tibia, humerus and radius was calculated for each of the above mentioned 8 sets of equations. For each population, it is expected that the following null hypothesis will not be rejected for the i-th equation:

$$H_0: \quad \bar{x}_{if}=\bar{x}_{it}=\bar{x}_{ih}=\bar{x}_{ir} ,$$

where $\bar{x}_{ij}$ (i=1, $\cdots$, 6 for males; i=1, 2 for females) is the mean estimated stature calculated using the i-th equation set for each different bone (j=f, t, h, r; f: femur; t: tibia; h: humerus; r: radius). This hypothesis was tested using analysis of variance, and when it was not rejected, it was considered permissible to pool the stature estimates based on the different bones. There are correlations between the four equations based on each of the femur, tibia, humerus and radius because they were derived from the data of the same individuals. These correlations may cause the underestimation of the difference between the four means, but this fact will not influence the conclusions.

As a measure of the differences between the four means, i.e., those for the femur, tibia, humerus and radius, the variance among them (df=3) was used. It was decided that when one set of equations gave the smallest variance, then the long bone length-stature proportion of the target population was closest to that of the population from which the equation set was calculated, thus those equations were the most appropriate for estimating the stature of the target population.

Results

Stature was estimated for each bone using the six equation sets for males and 2 equation sets for females. Mean estimated statures based on the femur, tibia, humerus and radius were calculated for modern Japanese, Kofun people, migrant type Yayoi people, Jomon people and modern Koreans. Tables 5 to 9 show the mean estimated statures based on each of the 4 bones, the results of F-tests of the significance of the difference among the 4 means, and the variance among them for each population.

(A) Modern Japanese (Table 5)

Table 5 shows that for females PEARSON's equations produced significant difference among the 4 means for the different bones, but FUJII's equations did not.

For males, the 4 means were not significantly different in FUJII's equations, TROTTER and GLESER's equations for Mongoloids and WANG *et al.*'s equations. Judging from the results of the F-tests and the variance among the 4 estimates, these three equation sets are adequate to estimate the stature of modern Japanese, but FUJII's equations based on modern Japanese data are the most appropriate, a priori.

The 4 means for statures estimated by FUJII's equations vary from 155.5 cm to 157.0 cm in males and from 145.5 cm to 147.2 cm in females. As the 4 estimated stature means, based on the different bones, were each calculated from the same individuals, the difference of 0.4–0.5 in variance can be considered within the range of sampling error.

The average stature of the present subjects is unknown, and their birth dates probably range from the 1880 s to the 1920 s. The average stature of the conscripts of this period is 156–158 cm. Estimated statures by FUJII's equations (155.5–157.0 cm) and by WANG *et al.*'s equations (157.2–158.5 cm) fall within this range, but the estimated statures based on TROTTER and GLESER's equations for Mongloids are obviously too tall (160.3–162.1 cm).

(B) Kofun people

In males the estimated stature means, based on the 4 bones, were not significantly

Table 5. Comparison of estimated height (cm) from four different bones based on different estimation equations. Modern Japanese.

Males

Bone	FUJII	PEARSON	STEVENSON	TROTTER & GLESER Mongoloid	TROTTER & GLESER Negroid	WANG *et al.*
Femur (N=42)	157.0	159.0	162.5	161.7	159.4	157.9
Tibia (N=42)	155.9	156.2	157.9	160.6	157.8	157.2
Humerus (N=42)	155.5	156.0	164.5	162.1	160.5	158.2
Radius (N=42)	156.1	158.7	163.2	160.3	159.2	158.5
variance (df=3)	0.40	2.54	8.23	0.74	1.23	0.31
F-test	ns	**	**	ns	*	ns

Females

Bone	FUJII	PEARSON
Femur (N=40)	147.2	147.7
Tibia (N=40)	145.5	145.9
Humerus (N=40)	146.9	147.3
Radius (N=40)	146.8	149.4
variance (df=3)	0.56	2.08
F-test	ns	**

ns: not significant; *: significant at the 5% level; **: significant at the 1% level.

different for the equations of FUJII, of TROTTER and GLESER for Mongoloids, and of WANG *et al.* The variance among the 4 means was the samallest in FUJII's equations (0.49), followed by TROTTER and GLESER's equations for Mongoloids (0.63). WANG *et al.*'s equations have greater variance because the means based on upper limb bones are greater than the means based on the lower limb bones, by 1–2 cm. The variances using FUJII's and TROTTER and GLESER's (Mongoloid) equations are not much different than those of the modern Japanese. However, as the estimated statures from TROTTER and GLESER's equations for Mongoloids are taller by 5 cm than those from FUJII's equations, it is clearly of great importance to use the correct equations.

Mean stature of the oriental subjects of TROTTER and GLESER was 168.7 cm, and that of Japanese of FUJII was 156.5 cm. The difference is as much as 12 cm. In estimations using regression equations, extrapolation should be avoided, but either set of equations would lead to extrapolation, because the mean long bone lengths of Kofun people are less than those of the oriental subjects of TROTTER and GLESER, and greater than those of FUJII's Japanese.

It is difficult to decide from the results of F-test and the variance among the 4 means, which equations, FUJII's or TROTTER and GLESER's (Mongoloid), are better for the Kofun people. I believe FUJII's equations are better for the following reasons: 1) the proportion of long bone lengths to stature of the Kofun people seems basically the same as that of the modern Japanese; 2) for modern Japanese, the estimated statures based on TROTTER and GLESER's equations for Mongoloids are about 5 cm taller, and the estimated statures using the equations of WANG *et al.* are 1–2 cm taller than those from FUJII's equations. It is the same for Kofun people; 3) the orientals of TROTTER and GLESER are geographically separate from the Kofun people.

Bilateral differences in the lower limb bones can be ignored, but the right upper limb bones are usually longer than their left counterparts. For example, in modern male Japanese mean bilateral difference in the maximum length of the femur is −0.45 mm (N=49) (HIRAI and TABATA, 1928; SEKI, 1931), but bilateral difference in the maximum length of the humerus is 1.77 mm (N=49) (MIYAMOTO, 1925; OHBA, 1934). The equations of PEARSON and STEVENSON are for right bones, but the Kofun materials include left bones, and their use might inflate the variance among the 4 means obtained from these equations. If the Kofun materials comprised only right bones, the mean estimates based on the upper limb bones would be a little greater. However, Table 6 shows that if the mean estimates based on the upper limb bones are greater as in the results based on PEARSON's and STEVENSON's equations, then the variance among the 4 means will be greater, too. Therefore, the larger variance in PEARSON's and STEVENSON's equations can not be attributed to the fact that the Kofun Materials include left bones.

Table 6. Comparison of estimated height (cm) from four different bones based on different estimation equations. Kofun people.

Males				TROTTER & GLESER		
Bone	FUJII	PEARSON	STEVENSON	Mongoloid	Negroid	WANG *et al.*
Femur (N=85)	160.8	162.0	166.3	164.8	162.4	161.9
Tibia (N=36)	159.5	159.6	162.3	164.2	161.2	161.3
Humerus (N=25)	159.8	159.9	168.3	165.9	164.3	162.9
Radius (N=12)	160.9	163.4	168.6	165.7	164.0	163.7
variance (df=3)	0.49	3.24	8.42	0.63	2.10	1.13
F-test	ns	**	**	ns	*	ns

Females Bone	FUJII	PEARSON
Femur (N=70)	148.6	148.8
Tibia (N=37)	147.5	148.0
Humerus (N=25)	147.3	147.7
Radius (N=15)	149.8	152.4
variance (df=3)	1.33	4.70
F-test	ns	**

ns: not significant; *: significant at the 5% level; **: significant at the 1% level.

For Kofun females, there are only two alternatives, FUJII's and PEARSON's equations. FUJII's equations are better because of the smaller and insignificant variance.

(C) Migrant type Yayoi people (Table 7)

For females, FUJII's equations did not yield significant difference among the 4 means, and the variance among them is about the same as that for modern Japanese.

Table 7. Comparison of estimated height (cm) from four different bones based on different estimation equations. Yayoi people.

Males				TROTTER & GLESER		
Bone	FUJII	PEARSON	STEVENSON	Mongoloid	Negroid	WANG *et al.*
Femur (N=49)	161.7	162.6	167.1	165.6	163.2	163.3
Tibia (N=44)	160.8	161.8	165.1	165.4	162.2	162.7
Humerus (N=35)	157.7	158.2	166.6	164.2	162.6	160.8
Radius (N=29)	160.5	163.0	168.1	165.1	163.5	163.3
variance (df=3)	2.98	4.79	1.56	0.38	0.34	1.41
F-test	**	**	ns	ns	ns	ns
variance (df=2)+	0.39	0.37	2.33	0.06	0.46	0.12
F-test	ns	ns	*	ns	ns	ns

Females Bone	FUJII	PEARSON
Femur (N=35)	151.3	151.2
Tibia (N=29)	150.6	152.1
Humerus (N=32)	150.0	150.9
Radius (N=29)	151.5	154.4
variance (df=3)	0.47	2.51
F-test	ns	**
variance (df=2)+	0.22	2.72
F-test	ns	**

+: Estimated height based on humerus excluded.
ns: not significant; * significant at the 5% level. ** significant at the 1% level.

For males, the equations of FUJII and PEARSON gave significant differences among the 4 means. Differing from modern Japanese and Kofun people, the variance among the 4 means is smaller with the equations of TROTTER and GLESER for both Mongoloids and Negroids, and with those of STEVENSON and of WANG *et al.* than with FUJII's equations. This means the long bone length-stature proportion of migrant type Yayoi people is closer to that of modern Chinese than to that of modern Japanese. Table 7 shows that this results from the fact that for FUJII's equations the estimated stature based on the humerus is smaller than those based on the other bones. A similar but much stronger tendency is observed in Jomon people as will be mentioned in the next section.

When the mean estimated stature based on the humerus is excluded, only STEVENSON's equations show significant difference among the 3 remaining means, and the variance among the 3 means is smallest for the equations of TROTTER and GLESER for Mongoloids, followed by WANG *et al.'s* equations.

Judging from F-test results, the variance among the 4 means and from racial affinity, the equations of TROTTER and GLESER for Mongoloids are the most suitable for migrant type Yayoi people.

(D) Jomon people

For both males and females, all the equations show significant difference among the 4 means. The smallest variance among the 4 means in males was 4.29 using TROTTER and GLESER's equations for Negroids, which is much greater than a variance of 0.40 for modern male Japanese obtained from FUJII's equations. It is clear from Table 8 that this is caused by the fact that in all the equations the mean estimated stature based on the humerus is much smaller than the mean estimated statures based on the other bones.

Table 8. Comparison of estimated height (cm) from four different bones based on different estimation equations. Jomon people.

Males				TROTTER & GLESER		
Bone	FUJII	PEARSON	STEVENSON	Mongoloid	Negroid	WANG *et al.*
Femur (N=68)	158.8	160.4	164.3	163.1	160.7	159.8
Tibia (N=61)	160.2	160.3	163.2	164.9	161.8	162.2
Humerus (N=74)	153.7	153.9	162.4	160.2	158.3	155.6
Radius (N=73)	160.2	162.6	167.7	164.9	163.2	162.8
variance (df=3)	9.53	14.09	5.45	4.92	4.29	10.68
F-test	**	**	**	**	**	**
variance (df=2)+	0.65	1.69	5.50	1.08	1.56	2.52
F-test	ns	**	**	**	**	**

Females		
Bone	FUJII	PEARSON
Femur (N=49)	147.8	148.1
Tibia (N=42)	149.0	149.5
Humerus (N=61)	146.1	146.3
Radius (N=57)	149.3	152.0
variance (df=3)	2.11	5.78
F-test	**	**
variance (df=2)+	0.63	3.90
F-test	ns	**

+: Estimated height based on humerus excluded.
ns: not significant; ** significant at the 1% level.

It has been pointed out that Jomon people have a higher radius length/humerus length ratio than modern Japanese, and are closer to Negroid and Australian aborigines in this respect (YAMAGUCHI, 1967). Usually the estimate based on the femur or tibia is the most reliable. The mean estimated stature based on the humerus is much less than that based on the femur or tibia. The mean estimated stature based on the radius is not much different than that based on the femur or tibia. Therefore, it can be concluded that Jomon people had a relatively shorter humerus rather than a longer radius, and that the estimated stature based on the humerus is an underestimate.

The significance of the difference of the means based on the femur, tibia and radius was tested. Table 8 shows that only FUJII's equations did not produce significant difference, and they have much smaller variance among the three means than the other equations. Therefore, FUJII's equations are the most suitable for Jomon people too, but with the condition that the humerus should not be used, as it underestimates the stature.

(E) Modern Koreans

Because sample size was small and the standard deviation of the femur lengths was not published, analysis of variance was not conducted for the females. In males the 4 means were significantly different for all the sets of equations. STEVENSON's equations had the smallest variance among the 4 means, but the mean estimated stature based on the femur is about 2 cm greater than that based on other bones, and this led to the significant difference among the 4 means. The reason for this might be sampling bias resulting from the much smaller number of femora.

Table 9. Comparison of estimated height (cm) from four different bones based on different estimation equations. Modern Korean.

Males				TROTTER & GLESER		
Bone	FUJII	PEARSON	STEVENSON	Mongoloid	Negroid	WANG *et al.*
Femur (N=64)	159.9	161.2	165.4	164.2	161.8	160.9
Tibia (N=136)	160.4	160.4	163.3	165.0	161.8	162.2
Humerus (N=115)	154.9	155.4	163.9	161.6	159.8	157.4
Radius (N=111)	156.4	159.0	163.5	160.7	159.5	158.8
variance (df=3)	7.05	6.68	0.89	4.23	1.57	4.56
F-test	**	**	*	**	**	**

Females Bone	FUJII	PEARSON
Femur (N=13)	147.0	147.5
Tibia (N=9)	146.5	146.9
Humerus (N=10)	144.6	144.7
Radius (N=10)	145.5	148.1
variance (df=3)	1.12	2.17

*: significant at the 5% level; **: significant at the 1% level.

Statures estimated by STEVENSON's equations, which have the smallest variance among the 4 means, range from 163.3 to 165.4 cm. The modern Korean materials came from Keijo Medical College, and the average stature of male Koreans in the 1930 s was about 165 cm in North Korea, about 163 cm in Central Korea and 162–163 cm in South Korea (ARASE *et al.*, 1934 a, 1934 b).

The equations of FUJII, WANG *et al.*, and TROTTER and GLESER for Mongoloids have greater variance among the 4 means, because the estimated stature based on the upper limb bones are considerably smaller than those based on the lower limb bones. This tendency is the most conspicuous in FUJII's equations for males.

It is hard to decide which mean estimated stature is the more reliable, that based on the femur or on the tibia. However, it may be safe to conclude that STEVENSON's equations based on North Chinese are better for modern Koreans than FUJII's equations based on modern Japanese or WANG *et al.*'s equations based on south-west Chinese.

Discussion

1. Pooling the stature estimates based on different bones

As shown by the results for the modern Japanese (Table 5), the mean estimated statures based on different bones can vary by up to 1.5 cm, even when the bones are from the same individuals, and when the equations were calculated from materials of the same racial group as the subjects. Therefore, it may be desirable to use only one specific bone. However, this approach may eliminate many imcomplete skeletons in the case of ancient populations. For example, for male Kofun people of eastern Japan, the sample size is 87 individuals when only femora are utilized, but it increases to 107 when all available bones are utilized. The loss of information about Yayoi people of eastern Japan is much greater when only femora are used, as they are more scarce. A greater number of subjects is always desirable for statistical analyses.

We try to estimate the stature of ancient people because stature carries information not only on overall body size, but also on the conditions which the individual experienced, such as nutritional status. If only one kind of bone is to be used, then it is not necessary to convert long bone length into stature. As the correlation with stature is higher in lower limb bones than in upper limb bones, whenever possible lower limb bones should be used. However, the present results indicate that for Japanese ancient populations the estimated stature based on upper limb bones is very close to the estimated stature based on lower limb bones when FUJII's equations are used and if humeri are not used for Jomon people. Therefore, it is unlikely that the mean estimated stature will be seriously biased by using upper limb bones when lower limb bones are not available. Actually femora tend to be preserved best for Kofun people, followed by tibiae (see Table 1). For Jomon people, radii will constitute about 15% of the total sample when lower limb bones are used preferentially. It is unlikely that their mean estimated stature is seriously influenced by including radii.

2. Secular change in limb bone length-stature proportion

Yayoi people excavated from North Kyushu and Yamaguchi Prefecture are tall and have long faces, and the difference between them and Jomon people is so great that their physical characteristics can not be explained unless the influence of migrants from the Asian Continent is taken into consideration (KANASEKI, 1976). Recent analyses of measurements of crania (HANIHARA, 1985; YAMAGUCHI, 1986 a) and of limb bones (YAMAGUCHI, 1986 b; TAGAYA, 1987) support this migrant hypothesis.

The present results indicate that the long bone length-stature proportion of Kofun people is basically the same as that of modern Japanese, and different from those of Yayoi people and Jomon people. The most conspicuous difference between Yayoi-Jomon and Kofun-modern people is that the former group has a shorter humerus, with this characteristic being more conspicuous in Jomon people. Another point revealed by the present study is that the long bone length-stature proportion of modern Japanese is similar to that of modern Mongoloid populations in the Asian Continent, though the Japanese are much shorter. This tendency first appeared in Yayoi people. In fact, that proportion in Yayoi people is closer to modern Mongoloid populations from the Asian Continent than it is to modern Japanese.

These two facts can be interpreted two ways. The first explanation is that the resemblance between Yayoi people and modern Mongloid populations in the Asian Continent is a phylogenetic similarity, and the long bone length-stature proportion observed in modern Japanese had been established by the Kofun period due to the influence of migrants from the Asian Continent. The second interpretation is that the proportion for migrant type Yayoi people is intermediate between those of Jomon people and Kofun people, and that because of changes in living conditions the Japanese have been losing their "archaic" characteristic of humeri being short.

Actually, both explanations are too extreme to be acceptable, for several reasons: the proportion for Jomon people is the closest to that of modern Japanese, except for the relatively shorter humerus. The reason why Jomon people have short humeri is not known. The resemblance of migrant type Yayoi people to modern Mongoloid populations from the Asian Continent has been indicated by many authors, but we have no knowledge about the secular changes of the long bone length-stature proportion which Koreans and Chinese may have experienced in the last several thousand years.

Recent studies on non-metric cranial traits indicate a resemblance between the Kofun people of eastern Japan and modern Koreans (YAMAGUCHI, 1985; DODO, 1987) but the present results suggest that the long bone length-stature proportion in Kofun people is not close to that of modern Koreans (see Tables 6 and 9).

Both genetic influences from the Asian Continent and changes in living conditions may have affected Jomon people, but I believe the influence of migrants was not very great as far as stature and body proportion are concerned, because the present results suggest considerable difference in mean stature and body proportion between migrant type Yayoi people and Kofun people.

3. Estimation equations for females

The present results indicate that TROTTER and GLESER's equations for Mongoloids are the most suitable for male Yayoi people, and that FUJII's equations are suitable for female Yayoi people. It seems indaequate to use the equations derived from the populations of different racial backgrounds for males and females, especially when the two sets of equations for males derived from these populations give average statures differing as much as 5 cm. However, using the equations for males to estimate the stature of a female individual is not adequate either, because body proportions differ according to sex. For FUJII's and PEARSON's equations, equations for males always give a greater estimated stature than the equations for females for a given bone within a range of normal variation of long bones. In other words, a female has longer long bones than a male of the same stature. Therefore, equations for males should not be used to estimate the stature of a female individual because they overestimate the female stature.

For females, there are only two alternative equation sets, and FUJII's and PEARSON's equations are based on a small number of subjects. Several sets of equations based on greater number of subjects from more varied groups are necessary in order to decide which equations are suitable for female ancient Japanese populations.

Summary and Conclusions

1. In order to choose the most suitable stature estimation equations for Japanese ancient populations, and to determine whether the mean estimated statures based on different bones can be pooled, four mean estimated statures were calculated based on the lengths of the femur, tibia, humerus and radius. The significance of the difference among the four means was tested and the variance among them was calculated for modern Japanese, Kofun people, migrant type Yayoi people, Jomon people and modern Koreans using eight sets of equations: by FUJII, PEARSON, STEVENSON, TROTTER and GLESER for Mongoloids, TROTTER and GLESER for Negroids, and by WANG *et al.*

2. For modern Japanese FUJII's equations are the most suitable a priori, and the results support this assumption.

3. FUJII's equations are also the most suitable for Kofun people, because they have the smallest variance among the four means for different bones and because the population from which they were calculated is the closest to Kofun people both geographically and racially.

4. For male migrant type Yayoi people, TROTTER and GLESER's equations for Mongoloids are the most suitable. According to these equations, the mean estimated stature of male Yayoi people is about 165 cm, which is 2–3 cm higher than usually believed.

5. The estimated stature of Jomon people based on the humerus is considerably less than that based on other long bones, for all the equations. FUJII's equations are considered to be most suitable for Jomon people when the estimated stature based on the humerus is excluded.

6. The femur or tibia should be used preferentially as they have higher correlations with stature than upper limb bones do. However, when lower limb bones are unavailable, the mean estimated stature would not be seriously biased by using upper limb bones in the above suggested equations provided that the humerus is not used for Jomon people.

7. PEARSON's equations have been most commonly used to estimate the stature of ancient Japanese populations, but the present results indicate that they are the least suitable for any Japanese population.

8. For females there are only two alternatives, FUJII's and PEARSON's equations. FUJII's equations are better for Japanese populations.

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Appendix 1. Kofun materials.

Males Site	Fem.	Tib.	Hum.	Rad.	Reference
Fukinbashi, Iwate			1		NOSAKA and ITO, 1984
Yamahata, Miyagi	1				HAYAMA, 1973
Konnaisan, Miyagi	2	1	3	3	HAYAMA, 1975
Tsukasawa, Miyagi	1				HAYAMA, 1976
Aoyama, Miyagi		1			DODO, 1981
Gomasawa, Fukushima	1	1			NAGAMORI, 1975
Zaruuchi, Fukushima	1				MORIMOTO and YOSHIDA, 1979
Kotaka-machi, Fukushima	1				MK, UMUT
Oodate-mura, Fukushima	1				MK, UMUT
Yamanoue, Fukushima				1	MK, UMUT
Sanmaizuka, Ibaraki	1				SUZUKI and SANO, 1960
Taisei, Ibaraki	2	1	1		SUZUKI and KIMURA, 1971
Hachigo, Ibaraki	1				MK, UMUT
Ootsu-machi, Ibaraki	2				MK, UMUT
Isige-cho, Ibaraki	1				MK, UMUT
Miyanakano, Ibaraki	2	1			MK, UMUT
Yamada, Chiba			1		MIZOGUCHI, 1982
Moritani Nagaami, Chiba	1				MK, UMUT
Shinbori, Chiba	1				MK, UMUT
Takano, Chiba	2	1			MK, UMUT
Kawarazuka, Chiba	1	1	1		MK, UMUT
Osada, Chiba	1				MK, UMUT
Monoi, Chiba	3				MK, NSM
Kusakari Kaizuka, Chiba	1	1	1	1	MK, NSM
Kijinodai, Chiba	5	5	2	1	MK, NSM
Komakidai, Chiba	1				MK, NSM
Todoroki, Tokyo	1		1		SUZUKI *et al.*, 1975
Hanesawadai, Tokyo	4	4			OGATA *et al.*, 1979
Tamagawa Noge, Tokyo	1				MK, UMUT
Unoki, Tokyo	2	3			MK, UMUT
Magomenishi, Tokyo	1				MK, UMUT
Ikegami Honmonji, Tokyo	1				MK, UMUT
Magome, Tokyo	2				MK, UMUT
Kamiikegami, Tokyo	1				MK, UMUT
Ekoda, Tokyo	1		1		MK, UMUT
Hirayama 1-go, Tokyo	1				MK, UMUT
Seijo Daigaku, Tokyo	1				MK, UMUT
Tonai A, Tokyo	1		1		MK, UMUT
Jindaiji, Tokyo	1	1			MK, UMUT
Nakano, Tokyo	2				MK, UMUT
Kokubunji, Tokyo		1			MK, UMUT
Oosawa, Tokyo	1	2	1		MK, NSM
Sanno 1-chome, Tokyo		1	1		MK, NSM
Sakahama, Tokyo		1		1	MK, NSM
Nakawada, Tokyo	1	1	1		MK, NSM

Appendix 1. (Continued)

Males

Site	Fem.	Tib.	Hum.	Rad.	Reference
Otozaka, Tokyo	2	1		1	MK, NSM*
Akabanedai, Tokyo	3	1	1	1	MK, NSM
Sengenjinja-nishi, Kanagawa	2	1		1	Kimura and Takahashi, 1972
Yamano, Kanagawa	1				MK, UK
Sinjuku, Kanagawa		1			MK, UK
Ichinotani, Kanagawa	1				MK, UMUT
Kamomejima, Kanagawa	4				MK, UMUT
Samukawa, Kanagawa	1	1	1		MK, UMUT
Ohurayama, Kanagawa	1	1			MK, UMUT
Simosakunobu, Kanagawa	2				MK, UMUT
Shinotani 16-go, Kanagawa	1				MK, UMUT
Ubagayatsu, Kanagawa	2				MK, NSM
Hamahata, Niigata				1	Norisawa, 1969
Ikkan-in, Ishikawa			1		Matsuda, 1960
Jogahira, Toyama	4				Morisawa and Matsuda, 1983, 1984
Jogahira, Toyama	5	2	4		MK, UK
Nishitaniyama, Fukui	1	1			Matsuda and Morisawa, 1984
Sanfuku, Gifu			1	1	MK, UK
Iwata, Shizuoka			1		MK, UMUT
Total	85	36	25	12	

Females

Site	Fem.	Tib.	Hum.	Rad.	Reference
Hachinohe-shi, Aomori	1	1			MK, UMUT
Konnaisan, Miyagi		1			Hayama, 1975
Aoyama dai-2, Miyagi		1			Dodo, 1981
Totsukayama, Yamagata	1				Baba *et al.*, 1983
Gomasawa, Fukushima			1		Nagamori, 1975
Kotaka-machi, Fukushima	1				MK, UMUT
Yamanoue, Fukushima	1		1		MK, UMUT
Mitsutsuka, Ibaraki	1		1		Suzuki, 1958
Taisei, Ibaraki	1	1			Suzuki and Kimura, 1971
Ohtsu-machi, Ibaraki	1				MK, UMUT
Nishimotodani, Chiba	1			1	Morisawa, 1976
Moridai, Chiba	1				Morimoto and Ogata, 1983
Moritani Nagaami, Chiba	1				MK, UMUT
Takano, Chiba	1	1			MK, UMUT
Osada, Chiba	1				MK, UMUT
Monoi, Chiba	1				MK, NSM
Ishikawa, Chiba	1	1			MK, NSM
Komakidai, Chiba	1				MK, NSM
Kijinodai, Chiba	5	4	2	1	MK, NSM
Nakaikegami, Tokyo	1				Yamaguchi, *et al.*, 1978
Hanesawadai, Tokyo		2			Ogata *et al.*, 1979
Kitami, Tokyo	1				MK, UMUT

Appendix 1. (Continued)

Females Site	Fem.	Tib.	Hum.	Rad.	Reference
Unoki, Tokyo	1		1	1	MK, UMUT
Kamitakada, Tokyo	1				MK, UMUT
Shinmei Shogakko, Tokyo	1				MK, UMUT
Magome, Tokyo	1				MK, UMUT
Kanekoyama, Tokyo	3	3	1		MK, UMUT
Kamiikegami, Tokyo	1				MK, UMUT
Jindaiji, Tokyo	1	1			MK, UMUT
Ouji Kishimachi, Tokyo	1				MK, UMUT
Nakano, Tokyo	1				MK, UMUT
Ohsawa, Tokyo	1				MK, NSM
Sakahama, Tokyo		1			MK, NSM
Sanno 4-chome, Tokyo	1			1	MK, NSM
Sakanishi, Tokyo	2	2	1		MK, NSM
Nakawada, Tokyo	2	1	1	1	MK, NSM
Otozaka, Tokyo	1	1			MK, NSM*
Akabanedai, Tokyo	1		1		MK, NSM
Sengenjinja-nishi, Kanagawa	2	2	1		KIMURA and TAKAHASHI, 1972
Ubagayatsu, Kanagawa	1		1		MK, NSM
Jogahira, Toyama	2				MORISAWA and MATSUDA, 1983, 1984
Jogahira, Toyama	3	3	3		MK, UK
Kitsunedani, Kyoto			1	1	JI
Hokki, Kyoto	1		1	1	JI
Komaruyama, Hyogo	1	1			JI
Tadachi, Hyogo	1				JI
Nishinoyama, Hyogo		1			JI
Isoma, Wakayama	2	2	4	4	JI
Uchinokawa, Wakayama		1			JI
Hase, Tottori	1				KINTAKA, 1929
Omuhara, Tottori	1				KINTAKA and KANASEKI, 1930
Mukaihara, Tottori		1			INOUE, 1982
Itotani, Tottori	1				JI
Nagasetakahama, Tottori	1			1	JI
Kurotori 2-go, Shimane			1		INOUE and INOUE, 1983
Hirano, Shimane	1	1	1		INOUE, 1983
Hongo Kamikuchi, Shimane	2	2		1	JI
Kume Mitsunari, Okayama	1	1	1	1	JI
Tonoyama, Okayama	1	1			JI
Katayama 1-go, Okayama	1				JI
Kitayama, Okayama	1				MK, UK
Ryuohzan, Hiroshima	1				SUZUKI and IKEDA, 1951
Yamanokami, Hiroshima				1	MUTO *et al.*, 1983
Asada, Yamaguchi	3		1		MATSUSHITA, 1982
Gozuka, Yamaguchi	1				MK, UK
Total	70	37	25	15	

MK: measured by the present author; JI: measured by Professor Jiro IKEDA, personal communication; UMUT: University Museum, University of Tokyo; NSM: National Science Museum; UK: University of Kyoto, Kiyono collection; *: with the permission from Dr. Hajime SAKURA;

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Appendix 2. Yayoi materials.

Males

Site	Fem.	Tib.	Hum.	Rad.	Reference
Minamikata, Okayama		1			IKEDA, 1981
Taishakukyo, Hiroshima	1				MK, UMUT
Doigahama, Yamaguchi	12	10	18	15	ZAITSU, 1956
Doigahama, Yamaguchi	2	2			MATSUSHITA *et al.*, 1983
Doigahama, Yamaguchi	2	2	2		NAGAI *et al.*, 1983
Doigahama, Yamaguchi	1		1		NAGAI *et al.*, 1984
Yoshimohama, Yamaguchi	3	3	3	3	NAKAHASHI and NAGAI, 1985
Ohnobaru, Fukuoka	1	1			KANASEKI and KAI, 1955
Morooka, Fukuoka				1	NAGAI, 1975
Sudare, Fukuoka	2				NAGAI, 1976
Tateiwa, Fukuoka	1				NAGAI, 1977
Kanenokuma, Fukuoka	7	14	5	9	NAKAHASHI *et al.*, 1985
Mitsu, Saga	7	5	4	1	USHIJIMA, 1954
Futatsukayama, Saga	7	5	2		MATSUSHITA, 1979
Yonnotsubo, Saga	2				WAKEBE, 1981
Ropponmatsu, Saga	1	1			MATSUSHITA *et al.*, 1984
Total	49	44	35	29	

Females

Site	Fem.	Tib.	Hum.	Rad.	Reference
Koshigasaki, Mie	1	1	1		MK, UMUT
Tonoyama, Okayama			1	1	JI

Appeneix 2. (Continued)

Females Site	Fem.	Tib.	Hum.	Rad.	Reference
Doigahama, Yamaguchi	14	10	18	14	ZAITSU, 1956
Doigahama, Yamaguchi	3	2	2		NAGAI *et al.*, 1983
Diugahama, Yamaguchi	2	2	1		NAGAI *et al.*, 1984
Yoshimohama, Yamaguchi	3	2	2	3	NAKAHASHI and NAGAI, 1985
Kanenokuma, Fukuoka	9	11	4	6	NAKAHASHI *et al.*, 1985
Mitsu, Saga	2	3	1	1	USHIJIMA, 1954
Futatsukayama, Saga	2	2	1		MATSUSHITA, 1979
Total	36	33	31	25	

MK: measured by the present author; JI: measured by Professor Jiro IKEDA, personal communication; UMUT: university museum, University of Tokyo;

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Appendix 3. Jomon materials.

Males

Site	Fem.	Tib.	Hum.	Rad.	Reference
Yoshiko, Aichi	28	35	37	36	ISHIZAWA, 1931; OHBA, 1935 a, b
Tsukumo, Okayama	16	12	18	14	KIYONO and HIRAI, 1928a, b
Ohta, Hiroshima	24	14	19	23	IMAMICHI, 1934, 1935
Total	68	61	74	73	

Females

Site	Fem.	Tib.	Hum.	Rad.	Reference
Yoshiko, Aichi	23	26	28	34	ISHIZAWA, 1931; OHBA, 1935 a, b
Tsukumo, Okayama	20	15	15	17	KIYONO and HIRAI, 1928 a, b
Ohta, Hiroshima	6	1	18	6	IMAMICHI, 1934, 1935
Total	49	42	61	57	

See reference for the literature.