四肢骨のPM・CT画像からの身長の推定の試み

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博士学位論文

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近畿大学大学院医学研究科
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Doctoral Dissertation

Stature estimation based on the lengths of the long bones of the extremities according to post-mortem computed tomography

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Abstract

Stature estimation is important for medicolegal personal identification. Since 1923, various Japanese researchers have attempted to produce formulae for estimating the stature of modern Japanese adults from the long bones of their extremities (the humerus, radius, ulna, femur, tibia, and fibula). Of these, the formulae developed by ANDOU in 1923, FUJII in 1960, and YOSHINO in 1986 are well known in forensic medicine as tools for stature estimation. However, these formulae are not suitable for estimating the stature of modern Japanese adults because they were all produced more than 20 years ago. In 2009, Hasegawa published an improved formula for estimating the stature of modern Japanese adults. The aim of the present study was to determine the optimal formula for stature estimation in modern Japanese adults. To this end, the lengths of the long bones of the extremities were measured in 335 Japanese cadavers (215 males and 120 females, mean age at death: 60.59 ± 18.74 years) using post-mortem computed tomography scan data obtained at Kinki University Faculty of Medicine Department of Legal Medicine from March 2009 through June 2013. Then, formulae for stature estimation were produced based on analyses of the data. In the whole population, the length of the right fibula displayed the strongest correlation with stature ($r = 0.9239$, $p<0.001$) according to Pearson's product-moment correlation coefficient. The lengths of all of the measured bones displayed strong correlations with stature. Therefore, the formulae developed in the present study are considered to produce more accurate estimates of the stature of modern Japanese individuals than the previously developed formulae. This study provides new formulae that can be used to estimate the stature of modern Japanese adults from the lengths of the long bones of their extremities.

Key words : Stature estimation, Long bones, PM-CT, CT scan imaging, Modern Japanese people, New formula

1. Introduction

Forensic analysis is important for the identification of deceased individuals in legal investigations. To identify an individual, it is necessary to determine their characteristics, such as their race, sex, age, stature, blood type, DNA, etc. In particular, stature is one of the most important characteristics for medicolegal personal identification [1-9, 12-28]. In Japan, various researchers have attempted to produce formulae for estimating the stature of modern Japanese adults from the long bones of their extremities (the humerus, radius, ulna, femur, tibia, and fibula). For example, ANDOU and FUJII published formulae based on the measurement of skeletal remains in 1923 and 1960, respectively [1, 8]. However, they used anatomical methods that required complete skeletons. In addition, the mean stature of Japanese individuals increased after World War II; therefore, the latter formulae became less valid. In 1986, YOSHINO developed improved formulae for stature estimation based on in vivo plain x-ray measurements [13]. They measured stature, as well as the lengths of the radius, ulna, tibia, and fibula, but did not measure the humerus or femur. Nevertheless, their formulae are well known to practitioners of forensic medicine and are often used to estimate stature in spite of them being unsuitable for modern Japanese adults. In an attempt to produce improved formulae for stature estimation in modern Japanese adults, HASEGAWA published new formulae based on in vivo measurements of the humerus, femur, and tibia obtained with dual-energy x-ray absorptiometry (DXA) in 2009 [24].

In March 2009, Kinki University Faculty of Medicine Department of Legal Medicine purchased a computed tomography (CT) scanner for scanning deceased individuals. Ever since, post-mortem computed tomography (PM-CT) scans have performed before each forensic autopsy. When a reasonably large number of these scans had been obtained, an attempt was made to use the PM-CT data to determine the optimal formulae for stature estimation in modern Japanese adults. The lengths of the humerus, radius, ulna, femur, tibia, and fibula are usually used to estimate stature. **Therefore, the lengths of these bones we measured on three-dimen-**sional (3D) PM-CT images obtained at Kinki University Faculty of Medicine Department of Legal Medicine from March 2009 through June 2013. After checking the errors between the actual measurements and the measurements obtained from the reconstructed 3D images, the validity of the abovementioned method was evaluated. Once the validity of the method had been confirmed, the relationships between each 3D bone measurement and the actual stature measurements were assessed, and appropriate regression formulae were derived. In addition, the strengths of the correlations between stature and each bone measurement were compared in order to identify the bone parameter that displayed the strongest correlation with stature.

2. Materials and methods

2.1. Materials

From 2009 onwards, PM-CT scans have been obtained before each forensic autopsy performed at Kinki University Faculty of Medicine Department of Legal Medicine (Table 1). From March 2009 through June 2013, a total of 335 Japanese deceased individuals (215 males and 120 females) were examined. Their mean age at death was 60.59 years (SD: 18.74; range: 20 to 99 years), and the mean ages of the males and females were 58.54 years (SD: 18.43; range: 20 to 91 years) and 64.24 years (SD: 18.81; range: 22 to 99 years), respectively.

The following bones did not have their lengths measured: the skull, scapula, vertebral column, and pelvis as well as any fractured bones. Stature was measured during autopsies performed by the medical coroner of Osaka Prefectural Police Coroner's Office.

The PM-CT scans (120 kV; 180 mA) were acquired using an Asteion4 TSX-012B scanner (TOSHIBA Medical, Tochigi, Japan). First, a tomogram of the skull (vertical height: 362 mm) was performed in axial mode. Then, an axial tomogram (vertical height: 1098 mm) of the region between the superior borders of the bilateral clavicles and the bilateral knee joints was obtained. All images were reconstructed with a slice thickness of 1 mm in the axial plan. Three-dimensional reconstructed images were obtained using the software Virtual Place Lexus 64 (AZE Co. Ltd., Tokyo, Japan) and used to measure the lengths of the humerus, radius, ulna, femur, tibia, and fibula. Each measurement was performed twice in order to reduce operator error.

Table 1. The age and sex distributions of the collected samples

Age	Male N(%)	Female N(%)	Whole population N(%)
20 - 29	21(9.8)	6(5.0)	27(8.1)
30 - 39	16(7.4)	12(10.0)	28(8.4)
40 - 49	27(12.6)	14(11.7)	41(12.2)
50 - 59	35(16.3)	7(5.8)	42(12.5)
60 - 69	54(25.1)	24(20.0)	78(23.3)
70 - 79	34(15.8)	31(25.8)	65(19.4)
80 - 89	25(11.6)	21(17.5)	46(13.7)
90 - 99	3(1.4)	5(4.2)	8(2.4)
Total	215(100)	120(100)	335(100)

2.2. Methods

After obtaining the above measurements, the measurement error between the actual sizes of the bones and the measurements obtained with 3D reconstruction was calculated for 18 skeletonized bodies, which were examined from March 2009 through December 2011. In total, 55 long bones were measured in this sample (humerus: 11, radius: 13, ulna: 12, femur: 11, tibia: 4 and fibula: 4). Then, the validity of the study method was evaluated using the least squares method.

After the validity of the method had been confirmed, images of each cadaver were analyzed. In order to improve measurement repeatability, the 2D CT scan axial images were subjected to a post-processing volume rendering technique, which produced 3D reconstructed bones with a thickness of 1 mm. Then, the following parameters were measured:

- Humeral length: the distance between the superior border of the head and the inferior border of the trochlea (Fig. 1).
- Radial length: the distance between the superior border of the head and the inferior border of the styloid process (Fig. 1).
- Ulnar length: the distance between the superior border of the olecranon and the inferior border of the styloid process (Fig. 1).
- Femoral length: the distance between the superior border of the head and the inferior border of the medial or lateral condyle (Fig. 1).
- Tibial length: the distance between the superior border of the medial or lateral condyle of the tibia and the inferior border of the medial malleolus (Fig. 2).
- Fibular length: the distance between the superior border of the apex of the head of the fibula and the inferior border of the lateral malleolus (Fig. 3).

All measurements were performed by the author.

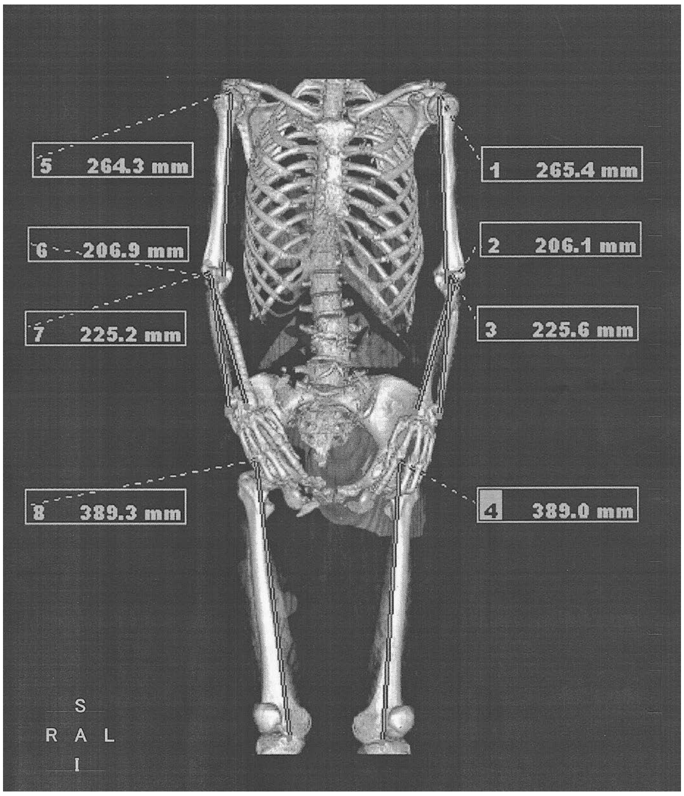

Fig. 1 Measurement of the long bones; 1: Left humeral length, 2: Left radial length, 3: Left ulnar length, 4: Left femoral length, 5: Right humeral length, 6: Right radial length, 7: Right ulnar length, 8: Right femoral length.

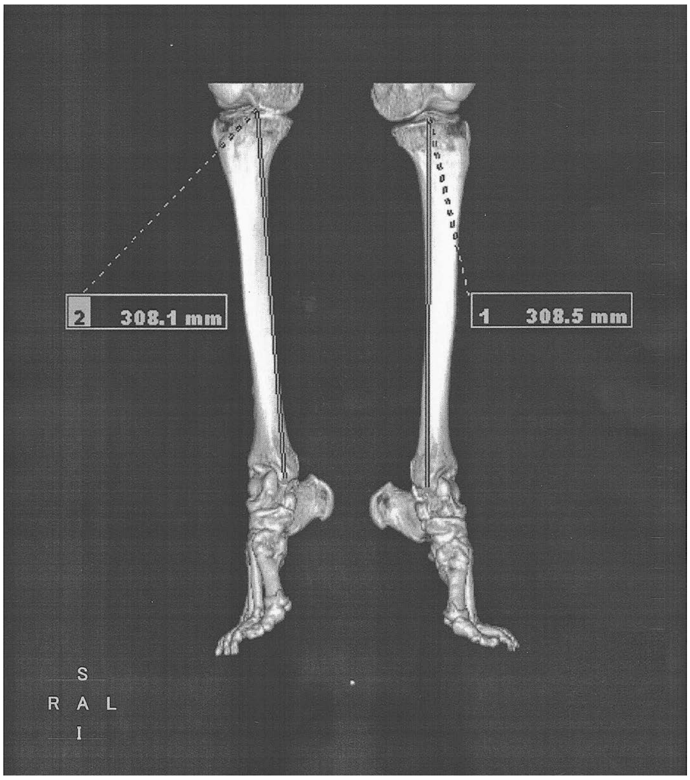

Fig. 2　Measurement of the long bones; 1: Left tibial length, 2: Right tibial length

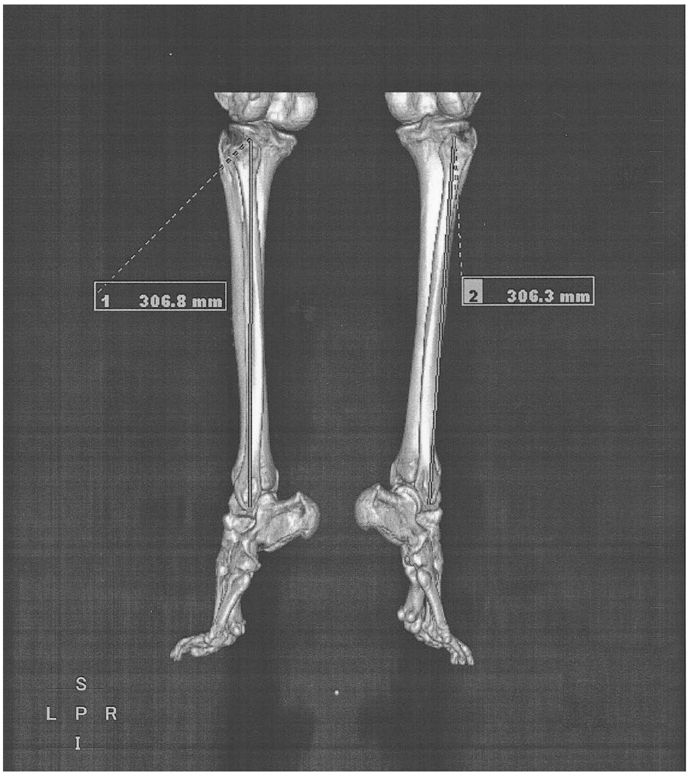

Fig. 3　Measurement of the long bones; 1: Left fibular length, 2: Right fibular length

3. Statistical analysis

The correlations between the lengths of each of the measured long bones and stature were examined by simple linear regression analysis using Pearson's product-moment correlation coefficient (r-value: r). Single linear regression was employed to analyze the correlations among the actual stature measurements and those predicted by the derived formulae (Fig. 4).

The following comparisons between the stature estimates derived from the 3D bone length data (XL) and the actual statures of the cadavers (YL) were performed:

- Linear regression based on the standard error between XL and YL;
- The differences between XL and YL were calculated for all 335 deceased individuals and represented on scatter diagrams.

All data were analyzed using Microsoft® Office Excel 2007 for Windows (©2006 Microsoft Corporation) and Statistical Package for the Social Science (SPSS) version 11.0J for Windows (SPSS Japan Inc., Tokyo, Japan).

The formulae produced in this study were derived from the abovementioned simple linear regression analysis.

4. Results

The mean measurement error was 0.068 ± 0.076 cm, the standard error of the mean was 0.0102 according to the least squares method, and the root mean square was 0.101. Therefore, the study method was considered valid.

Descriptive statistics for stature; age; and the lengths of the humerus, radius, ulna, femur, tibia, and fibula are presented for the whole population (males and females) (Table 2), males alone (Table 3), and females alone (Table 4). Each parameter exhibited a slight difference between males and females. When the bone measurements were compared between the left and right sides, no significant difference was detected for any parameter.

Based on these results, correlation coefficients were calculated and regression analyses were conducted. Tables 5-7 show the correlation coefficients for the relationships between stature and the lengths of each of the six long bones (humerus, radius, ulna, femur, tibia, and fibula). All of the bone measurements exhibited significant correlations with stature (p-value < 0.001). In the whole study population, the length of the right fibula exhibited the strongest correlation with stature (r-value = 0.9239, standard deviation (SD) = 3.6327), which was also the case in males (r-value = 0.8972, SD = 3.3327). However, in females the length of the left fibula displayed the strongest correlation with stature (r-value = 0.9055, SD = 3.3200). Simple linear regression was used to produce formulae that could be used estimate stature from the lengths of the examined long bones (Table 5－7).

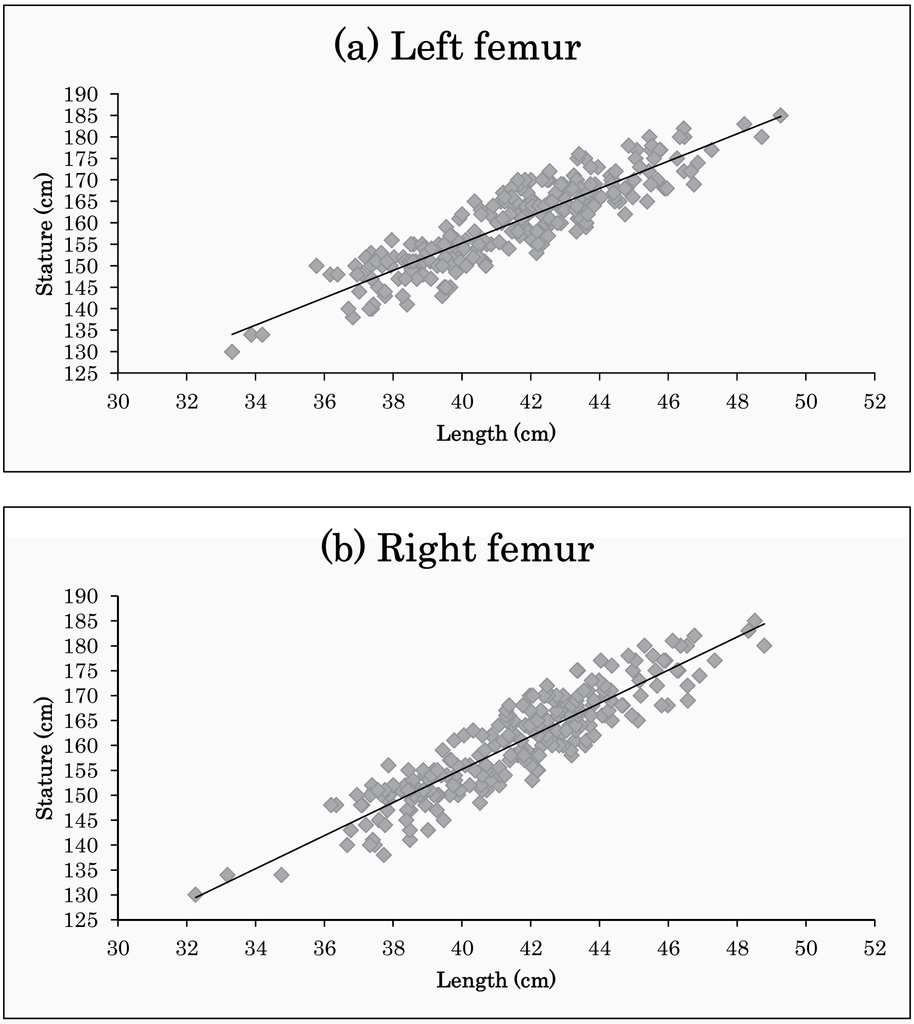

Fig. 4 Plot of actual stature as a function of bone length for (a) the left femur and (b) the right femur in the whole population.

Table 2. Basic age and measurement data of Japanese adults obtained from PM-CT scans

Variable		N	Mean	SD	Max.	Min.	Mean (Age)	SD (Age)	Mean (Stature)	SD (Stature)	r^2	p-value
Age		335	60.59	18.74	99	20						
Stature		335	161.08	9.98	185	130						
Humerus	L	180	29.38	2.19	34.62	22.7	57.81	19.05	162.81	10.12	0.7923	< 0.001
	R	172	29.28	2.18	34.67	22.81	57.81	19.60	162.26	10.14	0.8178	< 0.001
Radius	L	182	22.63	1.96	28.84	17.35	59.50	20.09	162.62	10.40	0.7885	< 0.001
	R	185	22.37	1.95	27.33	16.61	59.37	19.25	162.30	10.25	0.8121	< 0.001
Ulna	L	171	24.19	2.00	28.58	18.08	58.84	19.67	162.24	10.24	0.8066	< 0.001
	R	160	24.07	2.03	28.79	18.08	58.39	19.39	162.66	10.34	0.8426	< 0.001
Femur	L	250	41.55	2.83	49.27	33.32	61.49	18.96	160.17	10.05	0.7990	< 0.001
	R	253	41.56	2.75	48.79	32.26	61.64	18.44	160.37	10.09	0.8229	< 0.001
Tibia	L	131	34.50	2.57	40.62	25.73	57.31	20.04	164.03	9.25	0.8289	< 0.001
	R	130	34.43	2.62	40.67	25.33	57.11	20.24	163.87	9.51	0.8536	< 0.001
Fibula	L	131	34.54	2.56	41.04	25.58	57.31	20.04	163.99	9.23	0.8309	< 0.001
	R	128	34.47	2.63	40.57	25.27	57.20	20.39	163.82	9.53	0.8534	< 0.001

Stature and the lengths of the humerus, radius, ulna, femur, tibia, and fibula are shown in cm, and age is given in years.
L: left, R: right, SD: standard deviation, Max: maximum, Min: minimum, r^2: correlation of determination

Table 3. Basic age and measurement data of male Japanese adults obtained from PM-CT scans

Variable		N	Mean	SD	Max.	Min.	Mean (Age)	SD (Age)	Mean (Stature)	SD (Stature)	r^2	p-value
Age		215	58.54	18.43	91	20						
Stature		215	165.65	8.05	185	140						
Humerus	L	123	30.05	1.98	34.62	24.08	56.30	19.73	166.11	8.87	0.7523	< 0.001
	R	116	30.06	1.87	34.67	24.81	56.44	19.89	166.10	8.61	0.7425	< 0.001
Radius	L	131	23.23	1.67	28.24	17.78	58.53	19.77	165.27	9.49	0.7449	< 0.001
	R	127	23.14	1.62	27.33	18.71	58.57	19.37	165.72	9.10	0.7440	< 0.001
Ulna	L	122	24.82	1.68	28.58	19.33	57.91	19.00	165.57	9.14	0.7443	< 0.001
	R	112	24.81	1.72	28.79	19.39	57.25	19.08	166.20	8.86	0.7729	< 0.001
Femur	L	148	42.45	2.79	49.27	33.88	59.97	19.85	163.34	9.82	0.7817	< 0.001
	R	151	42.44	2.73	48.79	33.19	60.19	19.08	163.66	9.73	0.8041	< 0.001
Tibia	L	98	35.32	2.18	40.62	28.65	56.14	19.71	167.03	7.60	0.7703	< 0.001
	R	95	35.26	2.26	40.67	28.41	55.74	19.71	167.28	7.59	0.8050	< 0.001
Fibula	L	98	35.37	2.13	41.04	28.75	56.15	19.70	166.97	7.59	0.7391	< 0.001
	R	93	35.41	2.12	40.57	28.99	55.88	19.95	167.16	7.79	0.7872	< 0.001

Stature and the lengths of the humerus, radius, ulna, femur, tibia, and fibula are shown in cm, and age is given in years.
L: left, R: right, SD: standard deviation, Max: maximum, Min: minimum, r^2: correlation of determination

Table 4. Basic age and measurement data of female Japanese adults obtained from PM-CT scans

Variable		N	Mean	SD	Max.	Min.	Mean (Age)	SD (Age)	Mean (Stature)	SD (Stature)	r^2	p-value
Age		120	64.24	18.81	99	22						
Stature		120	152.88	7.57	180	130						
Humerus	L	57	27.93	1.91	32.98	22.7	61.05	20.22	155.70	8.98	0.7144	< 0.001
	R	56	27.66	1.88	31.96	22.81	60.64	18.86	154.31	8.31	0.7753	< 0.001
Radius	L	51	21.09	1.80	25.67	17.35	61.98	20.87	155.82	9.57	0.7550	< 0.001
	R	58	20.69	1.49	24.28	16.61	61.12	19.02	154.81	8.52	0.7774	< 0.001
Ulna	L	49	22.61	1.86	27.43	18.08	61.14	21.29	155.39	9.21	0.7910	< 0.001
	R	48	22.35	1.65	25.71	18.08	61.04	20.06	154.39	8.77	0.8096	< 0.001
Femur	L	102	40.23	2.33	46.47	33.32	63.70	17.45	155.58	8.54	0.7380	< 0.001
	R	102	40.26	2.24	46.55	32.26	63.79	17.33	155.51	8.59	0.7715	< 0.001
Tibia	L	33	32.06	2.15	37.62	25.73	60.76	20.92	155.14	7.95	0.7708	< 0.001
	R	35	32.16	2.17	36.44	25.33	60.83	21.45	154.61	7.96	0.7826	< 0.001
Fibula	L	33	32.07	2.10	37.44	25.58	60.76	20.92	155.14	7.95	0.8200	< 0.001
	R	35	31.97	2.20	36.47	25.27	60.71	21.41	154.93	7.95	0.7768	< 0.001

Stature and the lengths of the humerus, radius, ulna, femur, tibia, and fibula are shown in cm, and age is given in years.
L: left, R: right, SD: standard deviation, Max: maximum, Min: minimum, r^2: correlation of determination

Table 5 . Formulae for estimating stature in Japanese adults

Variable		Regression formula	±SE	r-value	p-value
Humerus	L	y = 4.12x + 41.77	±4.62	0.8901	< 0.001
	R	y = 4.21x + 39.07	±4.34	0.9043	< 0.001
Radius	L	y = 4.71x + 55.98	±4.79	0.8880	< 0.001
	R	y = 4.75x + 56.13	±4.45	0.9012	< 0.001
Ulna	L	y = 4.60x + 51.35	±4.51	0.8981	< 0.001
	R	y = 4.67x + 50.31	±4.12	0.9179	< 0.001
Femur	L	y = 3.18x + 28.08	±4.52	0.8939	< 0.001
	R	y = 3.32x + 22.23	±4.27	0.9071	< 0.001
Tibia	L	y = 3.27x + 51.12	±3.84	0.9104	< 0.001
	R	y = 3.35x + 48.45	±3.66	0.9239	< 0.001
Fibula	L	y = 3.29x + 50.45	±3.66	0.9115	< 0.001
	R	y = 3.35x + 48.35	±3.81	0.9238	< 0.001

y: stature; x: the length of the humerus, radius, ulna, femur, tibia, or fibula; both x and y are given in cm.
L: left, R: right, SE: standard error

Table 6 . Formulae for estimating stature in male Japanese adults

Variable		Regression formula	±SE	r-value	p-value
Humerus	L	y = 3.89x + 49.14	±4.43	0.8674	< 0.001
	R	y = 3.96x + 46.60	±4.34	0.8617	< 0.001
Radius	L	y = 4.90x + 51.55	±4.81	0.8631	< 0.001
	R	y = 4.85x + 53.44	±4.62	0.8626	< 0.001
Ulna	L	y = 4.69x + 49.09	±4.64	0.8628	< 0.001
	R	y = 4.53x + 53.72	±4.24	0.8791	< 0.001
Femur	L	y = 3.11x + 31.13	±4.60	0.8841	< 0.001
	R	y = 3.20x + 27.81	±4.32	0.8967	< 0.001
Tibia	L	y = 3.06x + 59.11	±3.66	0.8777	< 0.001
	R	y = 3.01x + 60.97	±3.37	0.8972	< 0.001
Fibula	L	y = 3.06x + 58.70	±3.61	0.8597	< 0.001
	R	y = 3.26x + 51.76	±3.90	0.8872	< 0.001

y: stature; x: the length of the humerus, radius, ulna, femur, tibia, or fibula; both x and y are given in cm.
L: left, R: right, SE: standard error

Table 7. Formulae for estimating stature in female Japanese adults

Variable		Regression formula	±SE	r-value	p-value
Humerus	L	y = 3.97x + 44.88	±4.84	0.8453	< 0.001
	R	y = 3.89x + 46.70	±3.97	0.8805	< 0.001
Radius	L	y = 4.61x + 58.60	±4.79	0.8689	< 0.001
	R	y = 5.04x + 50.51	±4.05	0.8817	< 0.001
Ulna	L	y = 4.40x + 55.86	±4.26	0.8894	< 0.001
	R	y = 4.80x + 47.22	±3.87	0.8998	< 0.001
Femur	L	y = 3.15x + 29.00	±4.39	0.8591	< 0.001
	R	y = 3.36x + 20.22	±4.12	0.8784	< 0.001
Tibia	L	y = 3.25x + 50.98	±3.87	0.8779	< 0.001
	R	y = 3.24x + 50.34	±3.77	0.8846	< 0.001
Fibula	L	y = 4.23x + 45.29	±3.81	0.9055	< 0.001
	R	y = 3.19x + 52.88	±3.43	0.8813	< 0.001

y: stature; x: the length of the humerus, radius, ulna, femur, tibia, or fibula; both x and y are given in cm.
L: left, R: right, SE: standard error

5. Discussion

Accurate stature estimation is important in forensic medicine. To date, several researchers have proposed formulae for estimating stature based on measurements of different long bones, the skull [15, 21, 22], and various short bones. In such studies, the femur was the most commonly measured long bone, whereas the sternum[27] and metatarsal bones [24] were the most frequently measured short bones. In addition, the femur exhibited the strongest correlation with stature [6, 7, 15, 17, 19, 21, 28], possibly because it remains well preserved many years after death.

Many of the previous studies of the relationships between stature and bone measurements have involved sample populations derived from a single country [1–9, 12–31]. Genetic and environmental components influence skeletal development; therefore, formulae derived from a certain population will not be suitable for stature estimation in populations from different nations or continents. In addition, the majority of the abovementioned studies were carried out on cadavers or skeleton collections [21].

In some cases, bone length was measured in vivo using anthropometric instruments. However, such instruments are not as precise as direct measurements. Some previous studies used radiography, CT, or DXA to obtain accurate standard in vivo bone length measurements [15, 26]. However, only two post-mortem studies, which were performed in Italy and China and involved skeletal populations, have been published [12, 16].

In Japan, ANDOU, FUJII, and YOSHINO have all produced formulae for estimating stature in forensic medicine [1, 8, 13]. However, these formulae are not suitable for modern Japanese adults because they were developed more than 20 years ago. In 2009, HASEGAWA developed improved formulae for stature estimation in modern Japanese adults [25, 26]. The aim of the present study was to determine the optimal formulae for stature estimation in modern Japanese adults using PM-CT scan data. CT is the most accurate radiographic technique for bone measurement [29, 30] and is considered to be very useful for stature estimation in cases in which it is necessary to identify a cadaver, such as those involving corpses in the advanced stages of decay, burnt bodies, etc. Most previous studies that attempted to develop stature estimation formulae were performed in vivo and involved young individuals; however, the subjects of the present study were all deceased. Therefore, there were no concerns about the radiation dose delivered during the CT scans. The formulae obtained in the present study are presented in Tables 5-7. The values produced by these formulae were lower than those calculated using previous formulae. The differences were considered to be due to variation between the sample populations, e.g., the subjects in the present study exhibited an older mean age and a shorter stature than those seen in previous studies [1, 8, 10, 11, 13, 26]. Specifically, the mean and stature of the present subjects were 58.5 years and 165.7 cm for the males and 64.2 years and 152.9 cm for the females, respectively. On the other hand, they were 35.8 years and 167.6 cm in males and 21.0 years and 157.8 cm in females, respectively, in the study by YOSHINO [10, 11, 13].

In the present study, only PM-CT CT scan data were collected. Using descriptive statistics, an attempt was made to elucidate the differences between males and females (p-value < 0.001). All of the measured parameters exhibited significant differences between males and females (p-value < 0.001) (Tables 5－7). In males, the length of the right tibia displayed a stronger correlation (r-value=0.8972) (Table 7) with stature than the lengths of the other long bones, whereas in females, the length of the left fibula exhibited the strongest correlation with stature (r-value = 0.9055) (Table 6). Overall, the length of the right tibia demonstrated the strongest correlation with stature in the whole population (r-value = 0.9239) (Table 5). The differences between the actual stature values and the stature estimates produced using the formulae for each bone length were also examined (Table 8).

Table 8. The differences between the actual stature measurements and the values predicted by the formulae developed in the present study

Variable		N (Both sexes)	Mean (Both sexes)	SD (Both sexes)	N (Males).	Mean (Males)	SD (Males)	N (Females)	Mean (Females)	SD (Females)
Humerus	L	180	3.775	4.60	123	3.580	4.39	57	4.076	4.75
	R	172	3.636	4.31	116	3.646	4.35	56	3.310	3.90
Radius	L	182	3.909	4.77	131	3.929	4.77	51	3.832	4.69
	R	185	3.643	4.43	127	3.741	4.59	58	3.400	3.98
Ulna	L	171	3.709	4.49	122	3.813	4.60	49	3.438	4.17
	R	160	3.347	4.09	112	3.415	4.20	48	3.217	3.79
Femur	L	250	3.751	4.50	148	3.826	4.57	102	3.591	4.35
	R	253	3.555	4.24	151	3.616	4.29	102	3.377	4.08
Tibia	L	131	3.167	3.81	98	2.967	3.62	33	3.266	3.75
	R	130	2.291	3.63	95	2.703	3.33	35	3.088	3.66
Fibula	L	131	3.103	3.78	98	3.147	3.86	33	2.873	3.32
	R	128	2.975	3.63	93	2.904	3.57	35	3.073	3.70

The lengths of the humerus, radius, ulna, femur, tibia, and fibula are shown in cm.
L: left, R: right, SD: standard deviation

Single regression analysis demonstrated that the formula for the right tibia provided the most accurate stature estimates. The present findings also suggested that other factors, such as the vertical heights of the skull and vertebral column, might have influenced the observed differences in stature between males and females.

The differences between the left and right sides of the body were also examined by comparing the maximum and minimum differences between the left and right r-values. The maximum difference was observed for the humerus in females (difference = 0.0352), and the minimum difference was associated with the radius in males (difference = 0.0005) (Table 9). The paired data were not complete because some of the individuals had been involved in traffic accidents or suffered bone fractures, etc. Therefore, the regression analysis of the paired data was only performed for the humerus in females and the radius in males. When the paired data were compared with the pooled unilateral data, it was found that the correlation coefficient for the relationship between humeral length and stature was decreased in females (n = 42, difference = 0.0065) and that for the relationship between radial length and stature was increased in males (n = 110, difference = 0.0010) (Table 9). However, when the difference between the left and right humeral correlation coefficients for females was compared with that between the left and right radial correlation coefficients in males, it was found that the variation between them was statistically insignificant.

Table 9. Formulae for estimating stature in female Japanese adults

Variable	D(Both sexes)	D(Males)	D(Females)	PD(Both sexes) / N	PD(Males) / N	PD(Females) / N
Humerus	0.0142	0.0057	0.0352	0.0031 / 147	0.0027 / 105	0.0065 / 42
Radius	0.0132	0.0005	0.0128	0.0010 / 153	0.0010 / 110	0.0063 / 43
Ulna	0.0198	0.0163	0.0104	0.0025 / 141	0.0086 / 101	0.0051 /40
Femur	0.0132	0.0126	0.0155	0.0001 / 239	0.0021 / 141	0.0040 / 98
Tibia	0.0134	0.0195	0.0193	0.0030 / 128	0.0031 / 96	0.0088 / 32
Fibula	0.0124	0.0275	0.0242	0.0024 / 127	0.0069 / 95	0.0096 / 32

D: The difference between the left and right r-values for the pooled unilateral data, PD: The difference between the left and right r-values for the paired data

6. Conclusions

Obtaining CT scans with a thickness of 1 mm is a valuable technique for measuring bone length. This is the first study to have used PM-CT scan-derived 3D images to measure bone length.

The goal of the present study was to develop new formulae for stature estimation in modern Japanese adults based on PM-CT scan data.

In conclusion, the present study demonstrates that the lengths of the long bones of the extremities (the humerus, radius, ulna, femur, tibia, and fibula) can be used to estimate the stature of modern Japanese adults.

The findings of this study suggest that long bone length measurements display strong correlations with stature and that there is very little difference in the strength of these correlations between the left and right sides. Note, whenever possible at least three long bones should be measured to estimate stature.

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