Bull. Natl. Mus. Nat. Sci., Ser. D, 37, pp. 35–48, December 22, 2011

Sex Assessment from the Talus and Calcaneus of Japanese

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Abstract The diagnosis of sex from an adult human skeleton is a fundamental task in the field of physical anthropology. In previous studies, the discriminant functions of the talus and calcaneus were shown to be useful tools for sexual assessment, giving accuracy ratios from 67 to 97%. The aim of this study is to apply these discriminant functions to modern Japanese with known sex, and to calculate new discriminant functions for the Japanese population using skeletal materials from 143 modern Japanese (72 males and 71 females). The total accuracy ratios of 7 published functions were below 70% and those of 5 functions were relatively high at 76–87%. The total accuracy ratios of the discriminant functions in this study ranged from 85% to 94%, which is somewhat higher than those of previous studies.

Key words :

Introduction

The determination of sex from an adult human skeleton is a fundamental task for forensic and physical anthropologists. In these fields, it is important to determine the sex of a human skeleton regardless of its state of preservation. The determination of the sex of a skeleton is based on three kinds of processes: DNA analyses, observation of morphological traits, and the use of metrical data with discriminant functions. Although the molecular methods demonstrate the greatest power for the determination of sex, they can fail when applied to ancient samples. The morphological methods are simple and show great accuracy (about 98% with pelvis and skull; Krogman, 1973). However, these methods tend to be subjective and depend on the experience of the observer. The application of discriminant analysis can reduce the subjectivity of sex determination and increase its accuracy, especially in cases with poor preservation (Hoyme and Iscan, 1989).

Nearly all bones in the skeleton have been studied to calculate discriminant functions (Safont et al., 2000). Among these studies, several have focused on the talus and/or calcaneus (Steele, 1976; Silva, 1995; Introna et al., 1997; Wilbur, 1998; Barrett et al., 2001; Murphy, 2002a; Murphy, 2002b; Bidmos and Dayal, 2003; Bidmos and Asala, 2003; Bidmos and Dayal, 2004; Bidmos and Asala, 2004; Gualdi-Russo, 2007). These studies indicated the utility of these foot bones for sexual assessment, with accuracy ratios from 67 to 97%.

Steele (1976) examined the talus and the calcaneus of 59 Euro-Americans (30 males and 29 females) and 60 African-Americans (30 males and 30 females) collected during the 1920s and 1930s with information on their sex and age-at-death, and 89 prehistoric Native Americans of unknown sex. These skeletal samples were obtained from the Terry skeletal collection stored at the Smithsonian Institution. He used 10 measurements and calculated 4 discriminant functions with accuracy between 79 and 89%. He stated the difficulty of applying these functions to modern American populations because of the secular changes among Americans in association with socioeconomic structure and stature. He also thought that these functions could be applied in cases with unknown ethnic origin because of their good results. Silva (1995) conducted a study on a large sample size, namely, 80 Portuguese males and 85 Portuguese females of known sex and age-at-death. These samples were obtained from the Identified Skeleton Collection of the Museum of Anthropology stored in the University of Coimbra. She established 21 discriminant functions with accuracy between 82 and 93% using 13 measurements of the talus and calcaneus. Introna et al. (1997) studied Southern Italian skeletal samples (40 males and 40 females) and calculated three discriminant functions with 8 measurements of right calcaneus. The accuracy of these functions reached about 85%. Wilbur (1998) calculated discriminant functions from 7 measurements of the talus and calcaneus defined by Steele (1976) in prehistoric Native American skeletal samples. Although the average accuracy of the talar and calcaneal measurements between three Native Americans groups was only 72%, the accuracy ratios with only talar measurements were between 82% and 87% and those with only calcaneal measurements were between 83 and 86%. Barrett et al. (2001) examined the secular change of the sexual dimorphism in the talus from the late Arctic Native Americans to the protohistoric Native Americans with 4 measurements of the talus. They calculated discriminant functions with accuracy ratios between 76 and 97%. Murphy (2002a, 2002b) examined prehistoric Polynesian skeletal samples (24 males and 27 females for the talus, 26 males and 22 females for the calcaneus) excavated in New Zealand and found that the accuracy ratios of discriminant functions were between 88 and 93% with the talus and between 85 and 93% with the calcaneus. Bidmos and Dayal (2003; 2004) used 9 talar measurements in 60 male and 60 female Euro-Africans and 60 male and 60 female native Africans. These samples were also obtained from the Raymond A. Dart Collection housed in the University of Witwatersrand with known sex and age-at-death. The discriminant functions that they established showed accuracy ratios of 73 to 89%. Bidmos and Asala (2003; 2004) utilized 9 calcaneal measurements in 53 male and 60 female Euro-Africans and 58 male and 58 female native Africans; their accuracy ratios of discriminant functions ranged between 69 and 92%. These samples were also from the Raymond A. Dart Collection. Gualdi-Russo (2007) examined 12 measurements of the talus and calcaneus in 62 male and 56 female Northern Italians with known sex and age-at-death, which were obtained from the Frassetto skeletal collection housed in the Museum of Evolution, University of Bologna. The accuracy ratios of the discriminant functions ranged between 88 and 96%. There is a report on the skeletal remains from the Fujinoki Kofun, which is a famous Japanese tumulus in Nara Prefecture dated to around the sixth century (Ikeda and Katayama, 1993). In this report, there were discriminant functions with 6 talar measurements or 5 calcaneal measurements, which were calculated by Akira Tagaya from studies of 29 males and 20 females from the Japanese skeletal collection stored at Kyoto University; their accuracy ratios reached 86%. This is the only report of discriminant functions for sex assessment with tarsal bones of East Asians. However, there is no detailed information about the calculation and no official report of these functions (Tagaya, personal communication).

These studies indicated that sex assessment with measurements of the talus and calcaneus was highly effective among many populations. In addition, the preservation of the talus and the calcaneus tend to be good even in ancient skeletal remains; the percentage at which they were preserved reached 44.3–51.1% at a Romano-British site (Waldron, 1987). This means that their analysis could increase the opportunity to assess the sex of skeletal remains. Although Steele (1976) stated that the discriminant functions could be applied to remains of unknown ethnic origin, Bidmos and Dayal (2004) concluded that osteometric differences exist between different population groups, and East Asians may have smaller tarsal bones than people of European or African origin, which may affect the results of the discriminant functions. The discriminant functions of tarsal measurements in an East

Asian population have not been reported from studies with a large sample size and in detail. Thus, the aim of this study is to apply the discriminant functions previously calculated in other populations to modern Japanese with known sex, and if necessary, to calculate new discriminant functions for Japanese populations using a large sample size.

Material and Methods

The 143 modern Japanese skeletal materials (72 males and 71 females) used in this study belong to the University Museum of the University of Tokyo and the Department of Anatomy, Chiba University School of Medicine. The sexes of all samples were recorded and the ages-at-death of all except 14 individuals were also recorded, which ranged from 14 to 78 years with an average of 38.7. Both right and left calcanei and tali were intact in these samples, which enabled examination of the laterality in talus and calcaneus. These individuals had no bone fracture, no osteoarthritis, and no other pathological changes.

Table 1 shows 13 measurements of the talus and 14 variables of the calcaneus measured with digital sliding calipers and an osteometric board in this study. These measurements were utilized in previous studies. All measurements basically follow the Martin definition (Baba 1991). Figures 1–9 illustrate these measurements. All measurements were taken on both right and left sides. For each variable, 10 repeated measures were made in a randomly chosen sample of 30 individuals, and their standard deviations were shown to be less than 0.2 mm.

At first, the one-sample Kolmogorov-Smirnov test was conducted for all variables in each sex to test for any deviations from the normal distribution. The distribution of all variables of each sex did not differ from normality at a statistically significant level. Therefore, parametric tests were performed for all statistical analyses. Paired t-tests were performed for the differences between sides. In addition, two-sample t-tests for sexual differences were performed.

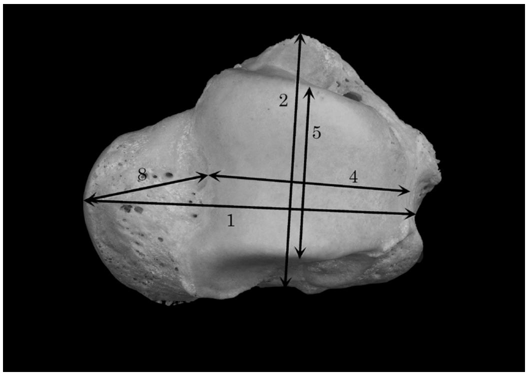

Fig. 1. Superior view of the talus illustrating the measurements of talar length (1), width of the talus (2), length of the trochlea (4), breadth of the trochlea (5), and head-neck length (8). The numbers on this figure indicate Martin's numbers.

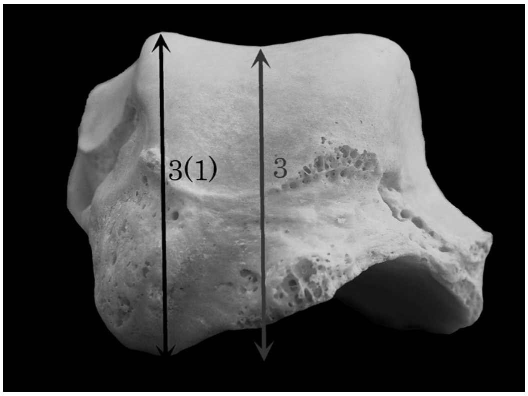

Fig. 2. Posterior view of the talus illustrating the measurements of talar height (3) and talar body height (3(1)). The numbers on this figure indicate Martin's numbers.

In order to select the discriminant functions previously reported, several criteria were set as follows: the functions were calculated using the skeletal samples with known sex, they were made from over 100 samples, and they showed the highest accuracy ratio through the stepwise discriminant analysis procedure in the talus and the calcaneus, the talus alone, and the calcaneus alone. The discriminant functions of Ikeda and Katayama (1993) were selected because these are the only functions calculated on a Japanese sam-

Table 1. Definition of measurements used in this study.

Martin No.	Measurement	Description	Figure
Talus			
1	Talar length	the projected distance from the most anterior point in the sulcus for the flexor halluces longus muscle to the most anterior point on the head. Steele (1976) and Silva (1995) mentioned the same definition of the measurement as “maximum length”. Although Bidmos and Dayal (2004) noted that the “tarsal length” was adapted from Martin’s definition, their “tarsal length” seems to be the “maximum tarsal length” (Martin No. 1a) according to their Figure 1, which illustrated the measurements.	Figure 1
2	Width of the talus	the maximum projected distance laterally/medially perpendicular to the sagittal plane. The lateral point is the most lateral point on the articular surface for the lateral malleolus and this line generally bisects the articular surface for the tibia slightly forward of the midpoint of the trochlea.	Figure 1
3	Talar height	the height of the talar body. The measurement is taken by placing the talus on a flat surface and determining the most superior point on the arc of the sulcus at the middle of the trochlea.	Figure 2
3(1)	Talar body height	the maximum height of the body. This measurement is also taken on a flat surface and determined using the most superior point of the articular surface of the trochlea. Steele (1976) and Silva (1995) mentioned the same definition of this measurement as “body height”.	Figures 2 & 5
4	Length of the trochlea	the maximum length of the trochlea articular surface at the midline that bisects the trochlear surface longitudinally. It is measured parallel to the sagittal axis of the trochlea	Figure 1
5	Breadth of the trochlea	the width of the upper trochlear surface at the midline that bisects the trochlear surface transversely, perpendicular to the length of the trochlea.	Figure 1
8	Head-neck length	the projected distance from the most anterior point of the head to the midpoint on the anterior margin of the trochlear surface.	Figure 1
9	Length of the head	the maximum length of the articular surface for the navicular bone parallel to the midline that bisects the articular surface in the anterior view.	Figure 3
10	Breadth of the head	the maximum breadth of the articular surface for the navicular bone perpendicular to the length of the head.	Figure 3
12	Length of the posterior articular surface for the calcaneus	the direct distance from the anterior-lateral intersection point of the midline of the posterior articular surface for the calcaneus and the margin of this articular surface to the posterior-medial intersection point of the midline and the margin.	Figure 4
13	Breadth of the posterior articular surface for the calcaneus	the maximum breadth of the posterior articular surface for the calcaneus perpendicular to the length of the posterior articular surface for the calcaneus.	Figure 4
14	Depth of the posterior articular surface for the calcaneus	the maximum depth from the length of the posterior articular surface for the calcaneus (Martin No. 12) to the deepest point of the posterior articular surface for the calcaneus.	Figure 4
—	Head height	the maximum height of the head of the talus. This measurements is taken on a flat surface and determined using the most superior point of the articular surface for the navicular bone.	Figure 5

Table 1. (Continued).

Martin No.	Measurement	Description	Figure
Calcaneus			
1	Maximum length of the calcaneus	the projected maximum distance from the most posterior point of the tuber calcanei to the most anterior/posterior point of the articular facet for the cuboid bone. This measurement is taken on a flat surface.	Figure 6
1a	Total length of the calcaneus	the projected distance from the most posterior point of the tuber calcanei to the center of the articular facet for the cuboid bone. This measurement is taken on a flat surface.	Figure 6
2	Breadth across the sustentaculum	the projected distance in the frontal plane and horizontal plane from the most lateral point of the posterior articular surface for the talus to the most medial point of the sustentaculum tali, perpendicular to the long axis of the calcaneus. This measurement is taken on a flat surface. Steele (1976) and Silva (1995) mentioned the same definition of the measurement as "load arm width".	Figure 7
3	Minimum breadth of the body	the projected distance of minimum horizontal breadth through the body of the calcaneus. This measurement is taken on a flat surface.	Figure 8
4	Height of the calcaneus	the projected height from the most inferior point of the tuber calcanei to the most inferior point of the concavity on the superior surface of the tuber calcanei.	Figure 6
4a	Calcaneal body height	the maximum projected height of the calcaneus from the most inferior point of the tuber calcanei to the most superior point of the calcaneus.	Figure 6
—	Minimum height of the body	the minimum distance from the most inferior point of the concavity on the superior surface of the tuber calcanei to the most superior point of the concavity on the plantar surface of the tuber calcanei. This definition was developed by Adachi (1904) and used by Ikeda and Katayama (1993).	Figure 6
5	Length of the body	the projected distance into the horizontal plane from the most posterior point of the tuber calcanei to the most anterior point of the posterior facet for the talus.	Figure 6
5a	Load arm length	the projected distance from the most posterior point of the posterior articular surface for the talus to the most anterior/superior point of the cuboidal facet.	Figure 6
7	Height of the tuber calcanei	the maximum projected height of the tuber calcanei, measured from the most superior point of the tuber calcanei to the most inferior point of the processus medialis tuberis calcanei.	Figure 9
8	Breadth of the tuber calcanei	the width of the tuber calcanei at the midpoint of the height of the tuber calcanei (Martin No. 7), perpendicular to the height of the tuber calcanei.	Figure 9
9	Length of the posterior articular surface for the talus	the direct distance from the anterior-lateral intersection point of the midline of the posterior articular surface for the talus and the anterior margin of this articular surface to the posterior-medial intersection point of the midline and the margin.	Figure 8
10	Breadth of the posterior articular surface for the talus	the maximum breadth of the posterior articular surface for the talus perpendicular to the length of the posterior articular surface for the talus.	Figure 8
13	Cuboid articular height	the maximum distance from the plantar margin of the articular surface for the cuboid bone to the dorsal margin of this articular facet.	Figure 7

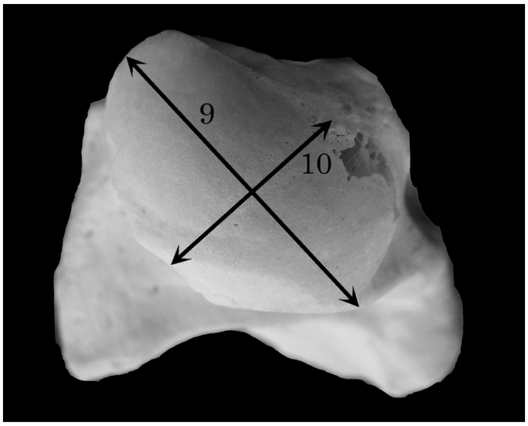

Fig. 3. Anterior view of the talus illustrating the measurements of length of the head (9) and breadth of the head (10). The numbers on this figure indicate Martin's numbers.

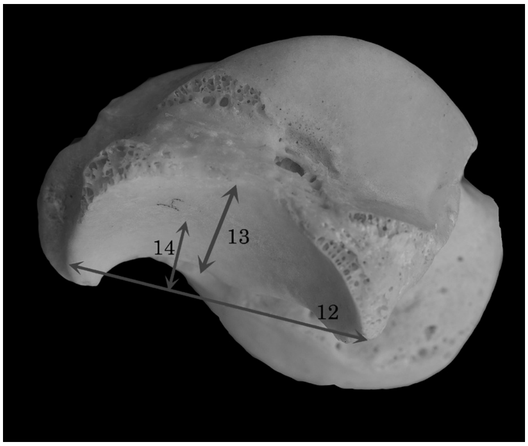

Fig. 4. Posterior-medial view of the talus illustrating the measurements of length of the posterior articular surface for the calcaneus (12), breadth of the posterior articular surface for the calcaneus (13), and depth of the posterior articular surface for the calcaneus (14). The numbers on this figure indicate Martin's numbers.

ple. Finally, 12 functions were selected for application.

Subsequently, direct discriminant analyses of all variables and stepwise discriminant analyses with modern Japanese were performed, and the discriminant functions, Wilk's lambda, and the correctly classified percentages were calculated.

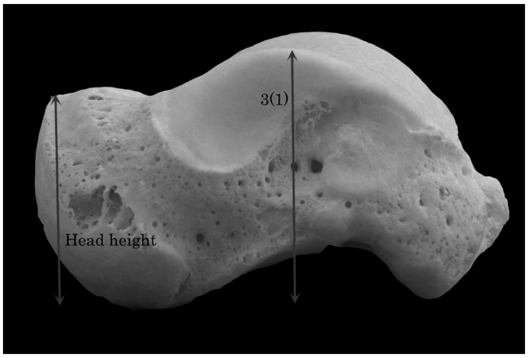

Fig. 5. Lateral view of the talus illustrating the measurements of head height and talar body height (3(1)). There is no Martin's number for head height.

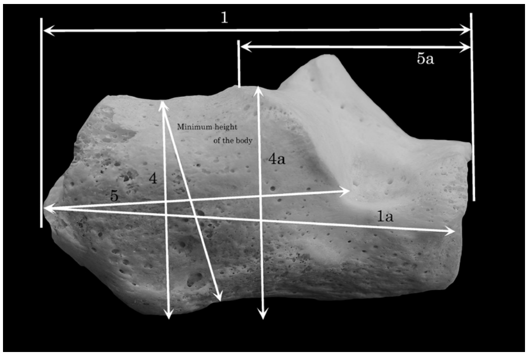

Fig. 6. Lateral view of the calcaneus illustrating the measurements of maximum length of the calcaneus (1), total length of the calcaneus (1a), height of the calcaneus (4), calcaneal body height (4a), minimum height of the body, length of the body (5), and load arm length (5a). The numbers on this figure indicate Martin's numbers.

Wilk's lambda is the ratio of the within-group to total sum of squares and a value of it that is close to zero implies high predictability of membership.

All statistical analyses were performed using the statistical software package SYSTAT 13.0.

Results

Table 2 shows a summary of the statistics, in which all mean values of males were significantly larger that those of females at the level of

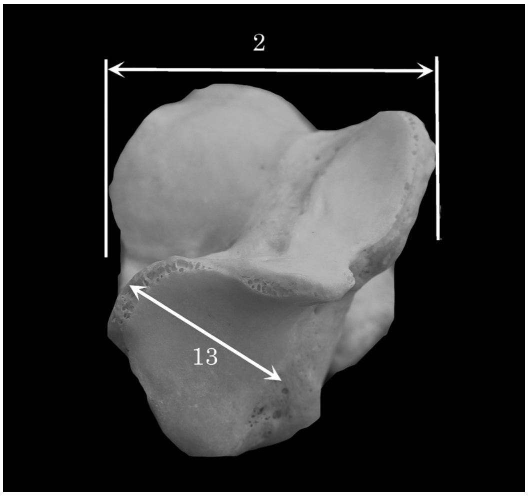

Fig. 7. Anterior view of the calcaneus illustrating the measurements of breadth across the sustentaculum (2) and cuboid articular height (13). The numbers on this figure indicate Martin's numbers.

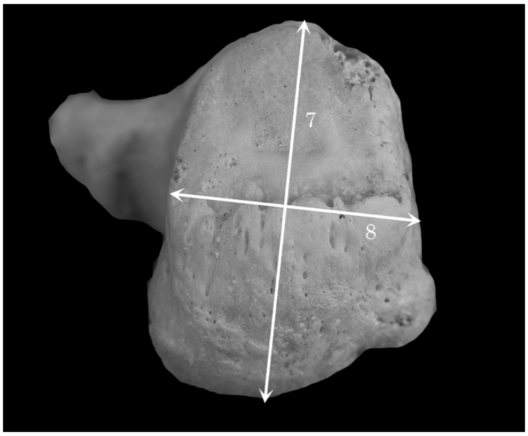

Fig. 9. Posterior view of the calcaneus illustrating the measurements of height of the tuber calcanei (7) and breadth of the tuber calcanei (8). The numbers on this figure indicate Martin's numbers.

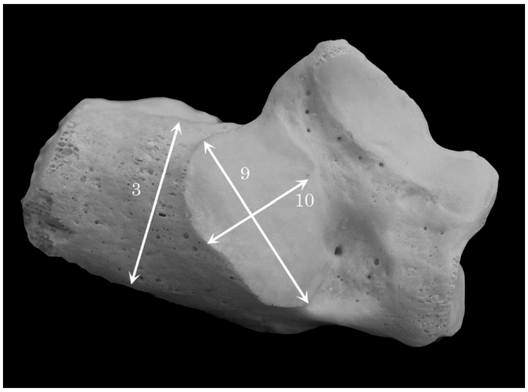

Fig. 8. Superior-lateral view of the calcaneus illustrating the measurements of minimum breadth of the body (3), length of the posterior articular surface for the talus (9), and breadth of the posterior articular surface for the talus (10). The numbers on this figure indicate Martin's numbers.

P=0.001. These results confirm the presence of significant sexual dimorphism in all variables of the talus and the calcaneus.

There are significant differences between right and left sides in 3 variables of the talus (tarsal length, tarsal head-neck length, and breadth of the posterior articular surface for the calcaneus) and 3 variables of the calcaneus (load arm length, breadth of the tuber calcanei, and length of the posterior articular surface for the talus). These results indicate that sexual assessment with metrical data of the talus and the calcaneus must be carried out bilaterally in the Japanese population.

The results of application of the discriminant functions that had good accuracy ratios for sex determination in previous studies on modern Japanese are summarized in Table 3.

Although the total accuracy ratios of 7 functions were below 70%, those of 5 functions were relatively high at over 76%. Basically, these results showed that the accuracy ratios for female individuals were extremely high, up to 90%, while those for males were low, under 50%. This means that the metrical sizes of the talus and the calcaneus in both Japanese males and females are smaller than those in the population with which the applied functions of extraordinary ratios were calculated. As Bidmos and Dayal (2004) pointed out, many discriminant functions can be population-specific. However, two functions established by Silvia (1995), one by Bimos and Dayal (2004), and one by Ikeda and Katayama (1993) showed good results for modern Japanese. Among them, the function for the size

Table 2. Summary statistics of all measurements.

			Male								Female							
			Right				Left				Right				Left			
			N	Means	S.D.		N	Means	S.D.		N	Means	S.D.		N	Means	S.D.	
Talus																		
	1	Talar Length	72	50.8	2.6	**	72	50.6	2.6	**	71	46.0	2.6	**	71	45.6	2.4	
	2	Width of the talus	72	40.6	2.4		72	40.8	2.3	**	71	36.8	1.8		71	36.7	1.8	
	3	Talar height	72	29.5	1.9		72	29.4	2.1	**	71	26.8	1.6	**	71	26.6	1.5	
	3(1)	Talar body height	72	31.9	1.9		72	31.9	1.9	**	71	28.7	1.6	*	71	28.5	1.5	
	4	Length of the trochlea	72	32.5	2.2		72	32.2	2.0	**	71	29.2	1.7	**	71	28.7	1.6	
	5	Breadth of the trochlea	72	28.8	1.5		72	28.7	1.5	**	71	25.7	1.7		71	25.6	1.4	
	8	Head-neck length	72	21.8	1.6	**	72	22.2	1.6	**	71	19.6	1.7	**	71	19.9	1.4	
	9	Length of the head	72	32.2	2.2		72	32.4	2.2	**	71	28.6	1.9		71	28.7	1.9	
	10	Breadth of the head	72	22.0	1.5		72	22.0	1.5	**	71	19.5	1.4		71	19.4	1.2	
	12	Length of the posterior articular surface	72	31.4	2.0		72	31.7	2.0	**	71	28.1	1.4		71	28.2	1.4	
	13	Breadth of the posterior articular surface	72	21.5	1.4	*	72	21.3	1.4	**	71	19.3	1.5	*	71	19.2	1.5	
	14	Depth of the posterior articular surface	72	7.2	1.1		72	7.2	1.0	**	71	6.2	1.0		71	6.2	0.9	
	—	Head height	72	26.5	1.9		72	26.4	1.8	**	71	23.3	1.7		71	23.3	1.7	
Calcaneus																		
	1	Maximum length of the calcaneus	72	73.9	3.6		72	73.8	3.7	**	71	67.7	3.0		71	67.8	3.0	
	1a	Total length of the calcaneus	72	69.7	3.3		72	69.7	3.4	*	71	63.6	3.0		71	63.5	2.9	
	2	Breadth across the sustentaculum	72	39.7	2.3		72	39.6	2.4	**	71	36.5	1.9		71	36.4	1.8	
	3	Minimum breadth of the body	72	26.3	2.5		72	26.2	2.5	**	71	23.6	2.2		71	23.4	2.1	
	4	Height of the calcaneus	72	38.0	3.3		72	37.9	3.4	**	71	34.1	2.4	*	71	33.9	2.3	
	4a	Calcaneal body height	72	43.4	2.7		72	43.5	2.8	**	71	39.0	2.0		71	39.2	2.0	
	—	Minimum height of the body	72	35.0	3.4		72	34.9	3.4	**	71	31.0	2.6		71	30.8	2.4	
	5	Length of the body	72	53.2	3.0		72	53.4	3.1	**	71	48.6	2.5		71	48.8	2.4	
	5a	Load arm length	72	46.4	2.6	*	72	46.9	2.9	**	71	42.4	2.2		71	42.6	2.2	
	7	Height of the tuber calcanei	72	44.9	3.1		72	44.9	3.0	**	71	40.0	2.5		71	40.0	2.5	
	8	Breadth of the tuber calcanei	72	30.3	2.0	**	72	30.0	2.0	**	71	26.5	2.1	**	71	26.2	1.9	
	9	Length of the posterior articular surface	72	28.9	2.0	**	72	29.3	2.1	**	71	26.1	1.5		71	26.0	1.5	
	10	Breadth of the posterior articular surface	72	21.7	1.7		72	21.5	1.5	**	71	19.5	1.6		71	19.4	1.7	
	13	Cuboid articular height	72	22.8	2.2		72	23.0	2.1	**	71	21.0	2.1		71	21.1	1.8	

"*" and "**" mean the results of the paired t-test between right and left sides and two-sample t-test between sex. "*" means $P<0.05$ and "**" means $P<0.0$, respectively.

Table 3. Results of the application of the discriminant functions in previous studies on modern Japanese.

Discriminatory functions	Paper	Population	Sample size	Original %correct	%correct for modern Japanese		
				Total	Female	Male	Total
(“Calcaneal body height”∗0.231)+(“Talar Length”∗0.319) +(“Width of the talus”∗0.513)−47.30	Steele (1976)	Euro-American and African-American	61 males, 59 females	89%	99%	42%	70%
(“Talar Length”∗0.420)+(“Width of the talus”∗0.411)−38.75	Steele (1976)			83%	99%	35%	66%
(“Talar Length”∗0.150)+(“Width of the talus”∗0.131) +(“Calcaneal body height”∗0.164)−20.43	Silva (1995)	Portuguese	80 males, 85 females	87%	99%	38%	68%
(“Length of the trochlea”∗0.286) +(“Breath of the trochlea”∗0.390)−19.20	Silva (1995)			85%	86%	89%	87%
(“Height of the tuber calcanei”∗0.126) +(“Breadth of the tuber calcanei”∗0.368)−16.33	Silva (1995)			86%	94%	65%	80%
(“Breadth of the tuber calcanei”∗0.314) +(“Maximum length of the calcaneus”∗0.081) +(“Breadth across the sustentaculum”∗0.159)−19.93	Bimos and Asala (2003)	Euro-African	53 males, 60 females	91%	100%	14%	57%
(“Talar Length”∗0.157)+(“Length of the posterior articular surface for the calcaneus”∗0.215) +(“Head-neck length”∗0.166)−19.26	Bimos and Dayal (2003)	Euro-African	60 males, 60 females	88%	99%	19%	59%
(“Length of the posterior articular surface for the talus”∗0.269) +(“Breadth of the posterior articular surface for the talus”∗∗ 0.184)+(“Cuboid articular height”∗0.272)−17.83	Bimos and Asala (2004)	Native African	58 males, 58 females	85%	93%	61%	77%
(“Talar body height”∗0.207)+(“Head height”∗0.295) +(“Length of the posterior articular surface for the calcaneus”∗0.229)−20.49	Bimos and Dayal (2004)	Native African	60 males, 60 females	87%	89%	86%	87%
(“Talar Length”∗0.146)+(“Breadth across the sustentaculum” ∗0.124)+(“Talar body height”∗0.174) +(“Maximum length of the calcaneus”∗0.065)−23.45	Gualdi-Russo (2007)	Italian	62 males, 56 females	94%	99%	24%	61%
(“Talar height”∗0.303)+(“Width of the talus”∗0.095) +(“Breadth of the trochlea”∗0.119)+(“Breadth of the head” ∗ 0.206)+(“Breadth of the posterior articular surface for the surface calcaneus”∗0.140)+(“Depth of the posterior articular for the calcaneus”∗ −0.361)−20.40	Ikeda and Katayama (1993)	Japanese	29 males, 20 females	86%	94%	68%	81%
(“Breadth across the sustentaculum”∗0.235)+(“Minimum breadth of the body”∗ −0.175)+(“Minimum height of the body”∗0.170)+(“Height of the tuber calcanei”∗0.157) +(“Breadth of the posterior articular surface for the talus”∗0.234)−19.55	Ikeda and Katayama (1993)			86%	7%	99%	53%

Total discriminatory scores less than 0 lead to classification as female.

Table 4. Unstandardized discriminant function coefficients, Wilks's lambda, and the percentage correctly classifed by direct discriminatory function analyses.

	All variables of right	All variables of left	All variables of right talus	All variables of left talus	All variables of right calcaneus	All variables of left calcaneus
Talus						
Talar length	−0.219	−0.048	−0.095	−0.037		
Width of the talus	−0.210	0.104	−0.161	0.076		
Talar height	−0.028	−0.158	−0.097	−0.167		
Talar body height	0.129	0.198	0.235	0.202		
Length of the trochlea	0.112	0.152	0.119	0.233		
Breadth of the trochlea	0.199	0.228	0.245	0.227		
Head-neck length	0.242	0.171	0.208	0.194		
Length of the head	0.032	−0.107	0.035	−0.129		
Breadth of the head	0.168	0.211	0.150	0.089		
Length of the posterior articular surface	0.476	0.208	0.364	0.220		
Breadth of the posterior articular surface	−0.096	−0.242	0.008	−0.134		
Depth of the posterior articular surface	−0.085	0.008	−0.047	0.041		
Head height	−0.039	0.074	−0.052	0.069		
Calcaneus						
Maximum length of the calcaneus	0.088	0.005			−0.047	−0.097
Total length of the calcaneus	0.165	0.161			0.196	0.206
Breadth across the sustentaculum	−0.148	−0.163			−0.104	−0.009
Minimum breadth of the body	−0.003	−0.076			−0.050	−0.091
Height of the calcaneus	−0.403	−0.121			−0.299	−0.158
Calcaneal body height	0.090	−0.106			0.139	−0.060
Minimum height of the body	0.248	0.109			0.160	0.142
Length of the body	−0.142	−0.110			−0.027	0.007
Load arm length	−0.023	0.026			0.061	0.116
Height of the tuber calcanei	0.138	0.064			0.141	0.114
Breadth of the tuber calcanei	0.057	0.110			0.141	0.197
Length of the posterior articular surface	0.012	0.067			0.140	0.135
Breadth of the posterior articular surface	0.114	0.117			0.131	0.073
Cuboid articular height	−0.066	−0.087			−0.067	−0.044
Constant	−22.716	−23.521	−21.775	−23.717	−21.094	−21.000
Wilks's Lambda	0.319	0.300	0.382	0.343	0.402	0.402
%correct						
Female	94%	93%	93%	96%	92%	90%
Male	93%	94%	92%	92%	85%	89%
Total	94%	94%	92%	94%	88%	90%

Total discriminatory scores less than 0 lead to classification as female.

of the tuber calcanei of Silvia (1995) and the function of Ikeda and Katayama (1993) show the bias that the accuracy ratios of females are higher than those of males. Thus, these functions of relatively high accuracy ratios were not suitable for assessment of sex in modern Japanese. It is interesting that the ratios of Silvia's function to the trochlear size and Bimos and Dayal's function were very high in both males and females. This result indicates that these functions can be applied for modern Japanese.

The results of direct discriminant analyses are shown in Table 4. All functions but one of the right calcaneus show high accuracy ratios over 90%. Table 5 shows the results of the stepwise discriminant function analyses. Its accuracy ratios reach over 87%. Basically, the left Wilks's lambdas are lower and the left accuracy ratios are

Table 5. Unstandardized discriminant function coefficients, Wilks's lambda, and the percentage correctly classifed by stepwise discriminatory function analyses.

	Right talus and calcaneus	Left talus and calcaneus	Right talus	Left talus	Right calcaneus	Left calcaneus
Talus						
Talar length	−0.140					
Width of the talus	−0.203		−0.148			
Talar height				−0.171		
Talar body height			0.202	0.171		
Length of the trochlea	0.137	0.232		0.240		
Breadth of the trochlea	0.248	0.217	0.262	0.214		
Head-neck length	0.220	0.227	0.155	0.201		
Length of the head						
Breadth of the head						
Length of the posterior articular surface	0.426	0.214	0.369	0.191		
Breadth of the posterior articular surface						
Depth of the posterior articular surface						
Head height						
Calcaneus						
Maximum length of the calcaneus						
Total length of the calcaneus	0.136	0.092			0.149	0.146
Breadth across the sustentaculum	−0.155	−0.163				
Minimum breadth of the body						
Height of the calcaneus	−0.163					
Calcaneal body height	0.164					
Minimum height of the body						
Length of the body						
Load arm length						0.128
Height of the tuber calcanei	0.139				0.118	
Breadth of the tuber calcanei					0.125	0.232
Length of the posterior articular surface						
Breadth of the posterior articular surface					0.153	
Cuboid articular height						
Constant	−23.440	−24.097	−21.725	−23.448	−21.626	−21.992
Wilks's Lambda	0.340	0.337	0.395	0.353	0.430	0.425
%correct						
Female	93%	96%	96%	96%	90%	92%
Male	92%	92%	88%	92%	83%	86%
Total	92%	94%	92%	94%	87%	89%

Total discriminatory scores less than 0 lead to classification as female.

higher than those on the right. In addition, the functions of the talus are better than those of the calcaneus. Table 6 shows the results of the discriminant function analyses with the same variables used in Silvia (1995) and Bimos and Dayal (2004). These results are very close to the results of the application of these functions (Table 3).

Discussion

This study has shown that measurements of the talus and the calcaneus can be useful for the assessment of sex in modern Japanese. This agrees with the results of previous studies (Steele, 1976; Silva, 1995; Murphy, 2002a; Murphy, 2002b; Bidmos and Dayal, 2003; Bidmos and Asala, 2003; Bidmos and Dayal, 2004; Bidmos and Asala, 2004; Gualdi-Russo, 2007). The

Table 6. Unstandardized discriminant function coefficients, Wilks's lambda, and the percentage correctly classifed by direct discriminatory function analyses with measurements of the talus and the calcaneus in previous studies

	Silvia's function of right	Silvia's function of left	Bimos and Dayal's function of right	Bimos and Dayal's function of left
Talus				
Talar length				
Width of the talus				
Talar height				
Talar body height			0.052	0.143
Length of the trochlea	0.238	0.287		
Breadth of the trochlea	0.440	0.451		
Head-neck length				
Length of the head				
Breadth of the head				
Length of the posterior articular surface			0.337	0.262
Breadth of the posterior articular surface				
Depth of the posterior articular surface				
Head height			0.255	0.256
Constant	−19.343	−20.998	−18.419	−19.785
Wilks's Lambda	0.464	0.411	0.463	0.427
%correct				
Female	85%	90%	92%	90%
Male	86%	86%	82%	85%
Total	85%	88%	87%	87%

	Silvia's function of right	Silvia's function of left
Calcaneus		
Maximum length of the calcaneus		
Total length of the calcaneus		
Breadth across the sustentaculum		
Minimum breadth of the body		
Height of the calcaneus		
Calcaneal body height		
Minimum height of the body		
Length of the body		
Load arm length		
Height of the tuber calcanei	0.175	0.165
Breadth of the tuber calcanei	0.307	0.335
Length of the posterior articular surface		
Breadth of the posterior articular surface		
Cuboid articular height		
Constant	−16.139	−16.397
Wilks's Lambda	0.493	0.485
%correct		
Female	90%	90%
Male	79%	82%
Total	85%	86%

Total discriminatory scores less than 0 lead to classification as female.

total accuracy ratios of the discriminant functions in this study ranged from 85% to 94%, which is somewhat higher than those of previous studies.

Since both the talus and the calcaneus are usually relatively well preserved, the discriminant functions of this study will be applicable in many cases. If these bones are intact, their use is desirable for application of the discriminant functions of all variables. The talus and the calcaneus have asymmetrical deviations in metrical size and the results of discriminant analyses in this study. In addition, the discriminant functions of the talus showed better predictive value than those of the calcaneus. These results indicate that, if possible, the discriminant functions of the left side and the talus (Table 4) should be used more, as they appear more reliable for the assessment of sex in Japanese individuals. In practice, functions with a reduced set of measurements obtained by a stepwise procedure (Table 5) would be more widely applicable because of the probability of some breakages of these bones. Among these functions, the function of left talus appears most reliable, with an accuracy ratio that reaches 94%.

Silva (1995) suggested that the discriminant functions with the size of the talar trochlea and the tuber calcanei were useful for incomplete and fragmentary talus or calcaneus. The results of this study indicate that these functions (Table 6) can be applied for Japanese with accuracy ratios of 85–88%.

Acknowledgments

I wish to express my gratitude to Dr. O. Kondo and Prof. G. Suwa (The University Museum of the University of Tokyo), Prof. C. Mori and Dr. Y. Matsuno (Chiba University School of Medicine), and Prof. A. Tagaya (Nagano College of Nursing) for permission to access skeletal materials and for their valuable advice. This study was supported by a Grant-in-Aid for Scientific Research (B) (No. 23405034).

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