Sexual determination of long bones in recent Japanese

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Abstract Sexual diagnosis of skeletons is of importance to physical and forensic anthropologists. The present study attempts to provide a basis from which one might choose a variable of a long bone that is most suitable in sexual assessments of skeletal material. A total of 47 variables of the humerus, radius, ulna, femur, and tibia of 64 recent-modern Japanese (32 male, 32 female) were investigated. The data were analyzed using the t-test and the stepwise discriminant analysis. The width of the articular surface of the distal humerus, the sagittal head diameter of the radius, the diaphyseal cross-section area or the articular breadth of the ulna, the bicondylar width or the transverse diameter of the lateral condyle of the femur, and the proximal epiphyseal breadth of the tibia were useful in sexual diagnosis of each of the long bones. Total accuracies of sex determination using these variables ranged from 91 to 95%. Among these measurements, sexual dimorphism tended to be greatest in the breadth diameters of the elbow and knee joints.

Key words: discriminant analysis, sex identification, epiphyseal diameters, recent Japanese

Introduction

Sex determination of the human skeleton has been studied in forensic and physical anthropology (Krogman, 1962). There are many studies on the metric diagnosis of sex in bones. Long bones have especially been used because of the ease of defining measurements, better preservation, and so on. Former studies have shown that some combination of diameters of the long bones have as strong a discriminatory power as do the pelvis or cranium (Pons, 1955; Hanihara, 1958).

In past studies, sex determination of individual or limited sets of long bones has been attempted. It has been pointed out that a certain set of variables tends to be better for sex diagnosis than others. There are some studies of sexual diagnosis using only the humerus (Iskan et al., 1998), the ulna (Purkait, 2001) and arm bones (Liu, 1989; Holman and Bennett, 1991; Mall et al., 2001). After Pons (1955), the femur is the most studied of all bones in the determination of sex (Van Gerven, 1972; Black, 1978; Dibennardo and Taylor, 1983; Asala, 2001), while there are some studies using only the tibia (Iskan and Miller-Shaivitz, 1984; Holland, 1991; Iskan et al., 1994). Liu et al. (1989) investigated three lower limb bones, the femur, tibia, and fibula. Dittrick and Suchey (1986) studied nine variables of the femur and nine variables of the humerus. Some studies considered all the long bones in their assessments of sex (Hanihara, 1958; Nakahashi and Nagai, 1986; Tagaya, 1987; Safont et al., 2000). In these studies, availability, group differences and the application of

discriminant functions were discussed.

In these past studies, it has been pointed out that epiphyseal or diaphyseal diameters of the long bones tend to have more power for sexual diagnosis than other variables like bone lengths. However there are limited discussions about which variable of which long bone may be the best discriminator of sex. Safont et al. (2000) showed that, among eight long bone shaft circumferences, tibial circumference at the nutrient foramen was the best variable in their discriminant analysis. Mall et al. (2001) demonstrated that, among nine variables of the long bones of the arm, humeral head diameter allowed the best distinction of sex. From a forward stepwise discriminant analysis of long bones of the arm, Liu (1989) considered that the sagittal head diameter of the radius was the best. Liu et al. (1989) concluded that upper epiphyseal length of the femur was the best among 37 variables of the long bones of the leg.

Thus, there are no fixed criteria regarding which variable(s) of which bone should be chosen in order to assess its sex. The purpose of this study is to investigate which variable of which long bone is the best in the metric diagnosis of sex.

Materials and Methods

The recent to modern Japanese skeletal materials used in this study belong to The University Museum, The University of Tokyo, and the Department of Anatomy, Chiba University School of Medicine. The sex and age of all individuals are known. In order to simplify the comparison between sexes, the sample size of each sex was made the same at 32 individuals. The sample was selected to range in age from closure of all epiphyses to 50 years. Only individuals with no bone fractures, no osteoarthritis, no periostitis,

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Table 1. The definition of variables for each bone

Variable	Explanation
Humerus	
length	Martin No. 1a
proximal length	vertical diameter of the proximal epiphysis (after Sakaue, 1997)
proximal breadth	M-L diameter of the proximal epiphysis (after Sakaue, 1997)
width of distal articular surface	Martin No. 12a
trochlear width	Martin No. 11
sagittal diameter of the trochlea	A-P diameter of the trochlea
distal length	vertical diameter of the distal epiphysis (after Sakaue, 1997)
distal breadth	M-L diameter of the distal epiphysis (after Sakaue, 1997)
mid-shaft area	solid cross-sectional area at the middle point of the length
Radius	
length	Martin No. 1
sagittal head diameter	Martin No. 5 (1)
transverse head diameter	Martin No. 4 (1)
distal maximum breadth	Martin No. 5 (6)
notch breadth	sagittal diameter of ulnar notch
mid-shaft area	solid cross-sectional area at the middle point of the length
Ulna	
length	Martin No. 1
trochlear notch height	Martin No. 7 (1)
notch depth	max depth from mid point of trochlear notch height to articular facet
upper articular breadth	Martin No. 6
lower articular breadth	maximum breadth of lower articular facet of the notch
radial notch breadth	Martin No. 9a
sagittal head diameter	Martin No. 11a
transverse head diameter	Martin No. 12a
mid-shaft area	solid cross-sectional area at the middle point of the length
Femur	
length	Martin No. 2
sagittal head diameter	Martin No. 19
medio-lateral head diameter	Martin No. 18
upper epiphyseal length	Martin No. 13
bicondylar width	Martin No. 21
antero-posterior diameter of the medial condyle	Martin No. 24b
antero-posterior diameter of the lateral condyle	Martin No. 22
transverse diameter of the medial condyle	Martin No. 21c
transverse diameter of the lateral condyle	Martin No. 21e
mid-shaft area	solid cross-sectional area at the middle point of the length
Tibia	
length	Martin No. 1a
antero-posterior diameter of the lateral articular surface	Martin No. 4b
antero-posterior diameter of the medial articular surface	Martin No. 4a
transverse diameter of the lateral articular surface	Martin No. 3b
transverse diameter of the medial articular surface	Martin No. 3a
proximal epiphyseal breadth	Martin No. 3
sagittal diameter of the distal epiphysis	Martin No. 7
transverse diameter of the distal epiphysis	Martin No. 6
maximum distal articular breadth	maximum A-P diameter of the distal articular facet
minimum distal articular breadth	minimum A-P diameter of the distal articular facet
distal articular breadth	maximum breadth of the distal articular facet without medial malleolus
mid-shaft area	solid cross-sectional area at the middle point of the length

See Baba (1991) for exact methods taken for Martin's measurements.

and no other apparent pathological changes were selected. A total of 46 measurements were examined (Table 1), and all measurements were taken on the right side. Mid-shaft areas were measured with Scion Image Beta 4.02, using sectioned molds of silicon putty. In selecting variables, one criterion considered was to diminish intra-observer error. For this purpose, for each variable 10 repeated measures were taken in a randomly chosen sample of 10 individuals, and the standard deviations of these were shown to be less than 0.1. Although shaft circumferences have often been included in previous

discriminant analyses, these were not considered in the present study because of poorer metrical repeatability.

Statistical analyses were undertaken as follows. First, the one-sample Kolmogorov-Smirnov test was conducted for all variables in each sex in order to test for any deviations from a normal distribution. Second, the t-values of the two-sample t-test were calculated in order to compare the relative significance of sexual difference between variables. The t-value can be seen as a quantitative distance between sexes if the sample sizes are the same. Prior to the discriminant anal-

ysis, the Box's M test was done for each long bone to test for equivalence of the covariance matrix. Third, discriminant analysis with one variable, and a forward stepwise discriminant analysis with all variables were conducted for each long bone. In the discriminant analysis with one variable, the Wilks' lambda and the correctly classified percentages were calculated. The Wilks' lambda is the ratio of the within-group and total sum of squares. Values close to zero imply high predictability of membership. All statistical analyses except the Box's M test were done with SYSTAT 10.0. The Box's M test was done with S.P.S.S. 11.0. A statistically significant level of 5% is referred to in the following descriptions of the present study.

Results

The distribution of all variables of each sex did not differ from normal at the statistically significant level. All variables showed statistically significant sexual differences in the two-sample t-tests. Results of the upper limb long bones are shown in Table 2. In the humerus, the t-values of the width of the distal articular surface and the distal breadth were higher than those of the other variables. The Wilks' lambda values were low, and the correctly classified percentages reached 94% in these variables. The t-value of humeral length was relatively low, and the correct percentage of clas-

sification of humeral length was one of the lowest of all the variables. In the radius, the t-value of the sagittal head diameter was the highest, and that of the transverse head diameter was second. The t-value of radial length was not as low as that of humeral length. The Wilks' lambdas of all radial variables except length and notch breadth did not exceed 0.4. The correctly classified percentages were higher than 80% in all variables of the radius. In the ulna, the t-value of mid-shaft area was the highest and its Wilks' lambda was the smallest. The t-values of the proximal articular breadths were also high. As in the radius, the t-value of ulnar length was not so low. All of the Wilks' lambda values exceeded 0.4 except for those of the lower articular breadth and mid-shaft area of the ulna, although the correctly classified percentages were not so low.

Results of the lower limb long bones are shown in Table 3. In the femur, the t-value of bicondylar width was the highest. The t-value of femoral length was the lowest of all the femoral variables. The Wilks' lambda values of bicondylar width and transverse diameter of the lateral condyle were the lowest, although their correctly classified percentages were not so high. The correctly classified percentages of all the femoral variables tended to be relatively low. In the tibia, the t-value and the correctly classified percentage of the proximal epiphyseal breadth were especially high, and its Wilks' lambda was very low. The t-value of tibial length was rela-

Table 2. Basic statistics and discriminant analysis of each variable in upper limb bones

Humerus	Mean		S.D.		t-value	Discriminant functions		Wilks' λ	Correctly classified (%)
	male	female	male	female		Raw coefficient	Constant		
length	294.45	273.73	14.27	13.75	5.92	0.071	-20.273	0.639	70.0
proximal length	33.68	31.54	2.83	1.74	3.65	0.425	-13.867	0.823	70.0
proximal breadth	48.39	42.86	2.62	1.97	9.56	0.432	-19.700	0.404	88.0
width of distal articular surface	44.92	38.01	1.96	1.93	14.20	0.514	-21.320	0.235	95.0
trochlear width	26.44	22.90	1.72	1.49	8.81	0.621	-15.329	0.443	70.0
distal length	24.88	22.65	2.61	1.70	4.07	0.454	-10.800	0.789	77.0
distal breadth	59.18	51.11	2.80	2.49	12.20	0.378	-20.817	0.294	94.0
sagittal diameter of the trochlea	25.98	21.96	1.70	1.28	10.71	0.665	-15.942	0.351	89.0
mid-shaft area	311.68	225.36	43.13	38.08	8.49	0.025	-6.600	0.457	88.0
Radius	Mean		S.D.		t-value	Discriminant functions		Wilks' λ	Correctly classified (%)
	male	female	male	female		Raw coefficient	Constant		
length	221.29	200.28	11.03	9.54	8.15	0.097	-20.440	0.482	80.0
sagittal head diameter	22.58	19.19	1.28	1.06	11.52	0.850	-17.753	0.318	92.0
transverse head diameter	21.39	18.47	1.36	0.82	10.37	0.888	-17.688	0.365	91.0
distal maximum breadth	27.97	24.65	1.40	1.16	10.33	0.778	-20.477	0.367	92.0
notch breadth	16.71	15.02	1.27	0.93	6.09	0.900	-14.283	0.625	88.0
mid-shaft area	116.40	84.27	14.19	12.30	9.67	0.075	-7.557	0.396	91.0
Ulna	Mean		S.D.		t-value	Discriminant functions		Wilks' λ	Correctly classified (%)
	male	female	male	female		Raw coefficient	Constant		
length	240.40	218.18	11.14	10.06	8.38	0.094	-21.608	0.469	83.0
trochlear notch height	22.97	19.72	1.98	1.75	6.96	0.535	-11.413	0.561	80.0
notch depth	12.08	10.41	1.15	1.15	5.85	0.873	-9.814	0.644	80.0
upper articular breadth	25.28	21.25	1.76	1.74	9.23	0.573	-13.326	0.421	84.0
lower articular breadth	25.36	20.96	2.05	1.51	9.78	0.555	-12.862	0.393	91.0
radial notch breadth	19.23	16.25	3.66	2.97	3.58	0.300	-5.323	0.829	72.0
sagittal head diameter	20.67	18.17	1.12	1.12	8.91	0.892	-17.316	0.438	88.0
transverse head diameter	17.67	15.09	1.43	1.26	7.68	0.744	-12.193	0.516	83.0
mid-shaft area	129.19	90.47	15.29	14.75	10.31	0.067	-7.313	0.385	92.0

Table 3. Basic statistics and discriminant analysis of each variable in lower limb bones

Femur	Mean		S.D.		t-value	Discriminant functions		Wilks' λ	Correctly classified (%)
	male	female	male	female		Raw coefficient	Constant		
length	404.26	375.00	20.47	20.64	5.69	0.049	-18.961	0.656	75.0
sagittal head diameter	45.25	40.21	2.19	2.00	9.63	0.477	-20.397	0.401	91.0
medio-lateral head diameter	45.61	40.49	2.24	1.95	9.75	0.479	-20.636	0.393	88.0
upper epiphyseal length	87.49	79.15	4.81	3.83	7.67	0.229	-19.116	0.513	81.0
bicondylar width	79.13	69.74	3.93	3.21	10.46	0.278	-20.699	0.361	91.0
antero-posterior diameter of the medial condyle	57.70	52.02	2.94	2.36	8.52	0.375	-20.598	0.461	81.0
antero-posterior diameter of the lateral condyle	60.53	54.35	2.45	2.75	9.50	0.384	-22.038	0.407	91.0
transverse diameter of the medial condyle	25.07	22.91	1.82	1.58	5.08	0.587	-14.086	0.705	70.0
transverse diameter of the lateral condyle	28.52	24.32	1.82	1.47	10.17	0.606	-16.001	0.375	88.0
mid-shaft area	504.29	397.71	59.58	45.58	8.04	0.019	-8.503	0.480	86.0

Tibia	Mean		S.D.		t-value	Discriminant functions		Wilks' λ	Correctly classified (%)
	male	female	male	female		Raw coefficient	Constant		
length	329.05	308.18	17.67	16.25	4.92	0.059	-18.770	0.719	72.0
antero-posterior diameter of the lateral articular surface	39.86	35.44	2.15	2.35	7.86	0.445	-16.746	0.502	89.0
antero-posterior diameter of the medial articular surface	46.56	41.35	3.15	2.33	7.53	0.361	-15.877	0.523	84.0
transverse diameter of the lateral articular surface	31.35	26.52	1.85	1.97	10.12	0.523	-15.145	0.377	92.0
transverse diameter of the medial articular surface	31.43	28.28	1.29	1.62	8.63	0.683	-20.402	0.455	86.0
proximal epiphyseal breadth	74.45	65.80	3.15	2.77	11.68	0.328	-22.989	0.333	94.0
sagittal diameter of the distal epiphysis	37.38	33.38	2.15	1.82	8.05	0.502	-17.760	0.489	86.0
transverse diameter of the distal epiphysis	47.93	42.41	2.50	1.92	9.91	0.448	-20.235	0.388	89.0
maximum distal articular breadth	31.63	28.56	2.01	1.44	7.02	0.572	-17.202	0.557	83.0
minimum distal articular breadth	25.16	23.96	2.31	1.59	2.42	0.505	-12.407	0.914	59.0
distal articular breadth	34.38	32.66	2.22	2.70	2.79	0.405	-13.567	0.889	61.0
mid-shaft area	418.79	318.55	50.30	39.98	8.82	0.022	-8.113	0.440	91.0

tively low.

Among all the variables, the best discriminators (high t-values, low Wilks' lambda, and high percentages of correct classification) were the width of the distal articular surface and the distal epiphyseal breadth of the humerus. Proximal epiphyseal breadth of the tibia was the next best discriminator. In general, epiphyseal breadths showed higher t-values than lengths in all the long bones, but this was less clear in the forearm bones. The t-values of the mid-shaft areas were moderately high in all the long bones.

There were no statistically significant differences between sexes, as examined by the Box's M test, in the covariance matrices of each of the long bones. Thus, the linear discriminant analysis can be applied to this data set. Tables 4 and 5 summarize the results of the multivariate discriminant analyses. The variables are listed in ascending order as determined by the forward stepwise procedure with all variables of each bone.

In the humerus, the distal epiphyseal diameters were relatively important in the determination of sex. This could be seen clearly by the fact that the correctly classified percentages reached 97% and did not change after step 2. Among the radial variables, the sagittal head diameter was the best.

It had a relatively strong discriminatory power so that the correctly classified percentage and Wilks' lambda did not change after step 2. In the ulna, the mid-shaft area and the upper articular breadth were good in sexual diagnosis. The correctly classified percentages of step 4 reached 97%. In addition to the ulna mid-shaft area and the upper articular breadth, the length of the ulna was important in the determination of sex.

In the femur, the transverse diameters of the distal epiphysis were good discriminators. The dimension of the lateral condyle was especially important in the determination of sex. However, the correctly classified percentages tended to be low and the Wilks' lambda was relatively high. Thus, in the present Japanese sample, the discriminatory power of the femur was inferior to that of the other long bones. In the tibia, the proximal epiphyseal breadth had the highest power in sexing. It was such an efficient discriminator that the correctly classified percentage reached 94%, and the Wilks' lambda was relatively low at the first discriminant step.

Compared across bones, the width of the distal articular surface and distal breadth of the humerus, the sagittal head diameter of the radius, and the proximal epiphyseal breadth of the tibia were most prominent in discriminating sex.

Table 4. Summary of stepwise procedure with all variables in each upper limb bone

Step	Humerus	Wilks's lambda	Correctly classified (%)
1	width of distal articular surface	0.235	95.0
2	distal breadth	0.221	97.0
3	trochlear width	0.215	97.0
4	mid-shaft area	0.211	97.0
5	distal length	0.209	97.0
6	proximal length	0.207	97.0
7	sagittal diameter of the trochlea	0.204	97.0
8	proximal breadth	0.203	97.0
9	length	0.203	97.0
Step	Radius	Wilks's lambda	Correctly classified (%)
1	sagittal head diameter	0.318	92.0
2	mid-shaft area	0.275	94.0
3	distal maximum breadth	0.267	95.0
4	length	0.261	94.0
5	notch breadth	0.261	95.0
6	transverse head diameter	0.261	95.0
Step	Ulna	Wilks's lambda	Correctly classified (%)
1	mid-shaft area	0.368	92.0
2	upper articular breadth	0.312	95.0
3	length	0.292	95.0
4	trochlear notch height	0.288	97.0
5	sagittal head diameter	0.286	97.0
6	notch depth	0.283	97.0
7	lower articular breadth	0.282	97.0
8	transverse head diameter	0.281	97.0
9	radial notch breadth	0.281	97.0

Among the remaining variables, the upper articular breadth of the ulna and the bicondylar breadth of the femur were also good discriminators, suggesting that the variables most suitable for sexual determination are concentrated in the breadths of the elbow and knee joints. Table 6 shows the result of discriminant analysis using the best variables of each bone. In this analysis, the width of the articular surface of the humerus and the proximal epiphyseal breadth of the tibia were selected in the forward stepwise analysis.

Discussion

The purpose of this study was to investigate which variable of which bone is the best for the metric diagnosis of sex in long bones. Judging from the t-values and the results of the stepwise discriminant analysis, the width of the distal articular surface of the humerus, the sagittal head diameter of the radius, the mid-shaft cross-sectional area or the lower articular breadth of the ulna, the bicondylar width of the femur, and the proximal epiphyseal breadth of the tibia can be considered to be the most useful for sexual diagnosis in each of the long bones. Especially the breadth diameters of the distal epiphysis of the humerus and the proximal epiphyseal of the tibia were powerful discriminators, judging from the Wilks' lambda values and the correctly classified percentages. The present study also showed that epiphyseal

Table 5. Summary of stepwise procedure with all variables in each lower limb bone

Step	Femur	Wilks's lambda	Correctly classified (%)
1	bicondylar width	0.362	91.0
2	transverse diameter of the lateral condyle	0.324	94.0
3	antero-posterior diameter of the lateral condyle	0.310	94.0
4	length	0.298	95.0
5	mid-shaft area	0.294	98.0
6	antero-posterior diameter of the medial condyle	0.292	97.0
7	medio-lateral head diameter	0.291	97.0
8	sagittal head diameter	0.289	95.0
9	transverse diameter of the medial condyle	0.289	95.0
10	upper epiphyseal length	0.289	95.0
Step	Tibia	Wilks's lambda	Correctly classified (%)
1	proximal epiphyseal breadth	0.313	94.0
2	mid-shaft area	0.292	94.0
3	length	0.280	95.0
4	transverse diameter of the lateral articular surface	0.271	94.0
5	antero-posterior diameter of the medial articular surface	0.265	94.0
6	transverse diameter of the distal epiphysis	0.258	95.0
7	distal articular breadth	0.248	97.0
8	minimum distal articular breadth	0.242	97.0
9	transverse diameter of the medial articular surface	0.238	95.0
10	sagittal diameter of the distal epiphysis	0.235	97.0
11	antero-posterior diameter of the lateral articular surface	0.234	95.0
12	maximum distal articular breadth	0.234	95.0

Table 6. Summary of stepwise procedure with the best variables in each long bone

Step	Bone	Variable	Wilks's lambda	Correctly classified (%)
1	Humerus	width of distal articular surface	0.235	95.0
2	Tibia	proximal epiphyseal breadth	0.226	97.0
3	Ulna	mid-area	0.220	98.0
4	Radius	sagittal head diameter	0.218	98.0
5	Femur	bicondylar width	0.215	98.0

parts tend to be more useful for sex determination than the length of long bones. Since Dwight (1904/05) pointed this out almost a century ago, the importance of the diameters of the epiphyseal parts has been accounted for by previous studies (e.g. Dittrick and Suchey, 1986). In the present study, it was further found that sexual differences are especially strong in the breadth diameters of the elbow and knee joints.

There are many reports from past studies that support this conclusion. In the humerus, the distal breadth has been

pointed out either directly or indirectly as good for sexing (Dwight, 1904/05; Dittrick and Suchey, 1986; Liu, 1989; Iscan et al., 1998; Mall et al., 2001). Liu (1989) and Mall et al. (2001) pointed out the discriminatory power of radial head diameters. Van Gerven (1972) studied 17 variables of the femur and found that epicondylar breadth was the most powerful in sexing. Liu et al. (1989), Holland (1991) and Iscan et al. (1994) concluded that the epiphyseal breadth of the tibia was better than the other variables of that bone in sexual diagnosis.

There are, however, some differences between the results of this study and those of some of previous studies. In particular, the head diameters of the humerus and femur have previously been reported as good indicators of sex (Dibennardo and Taylor, 1983; Dittrick and Suchey, 1986; Liu, 1989; Liu et al., 1989; Iscan et al., 1998; Mall et al., 2001). In the present study, these variables were not as good a discriminator as the breadths of the elbow or knee joints. In another study, Safont et al. (2000) showed that the circumference at the nutrient foramen of the tibia was the best variable in a discriminant function, and the tuberosity circumference of the radius was second. This difference of results cannot be easily interpreted, because the measurements of the bone shafts differ between that and the present studies.

Holland (1991), who investigated sex determination with the proximal tibia, noted that "because the ends of the tibia are subjected to heavy stress during an individual's life, and because the stress may have a sexual component, the ends should be useful in determining sex." But, in the present study, the diaphyseal cross-sectional areas that should also reflect mechanical stress were not as good a discriminator as the epiphyseal parts, and the distal humerus was better than the proximal tibia. This suggests that sexual differences in the size of the epiphyseal parts are not simply due to the difference of mechanical stresses that may occur at a particular joint. It is of interest to note that sexual dimorphism has been known to occur in the carrying angle of the elbow and the bicondylar angle of the femur. The relationship of these angular distinctions with the size dimorphism demonstrated above remains to be investigated.

In practice, there are some problems in applying the functions derived in this study to the sexing of the long bones of Japanese skeletal remains of unknown sex. As Iscan et al. (1994) noted the modern Japanese differ in size from that of the recent to modern skeletal series, such as those used in this study. Tagaya (1987) also pointed out population differences of sexual dimorphism among recent Japanese samples. Thus, care must be taken in directly applying the functions of this study. However, the systematic investigation of the present study and the corroborating published evidence summarized above on a wide range of skeletal series provide some insight. It is widely recognized that considerable sexual dimorphism occurs in the carrying angle of the elbow and the bicondylar angle of the femur. The results of the present study strongly suggests that epiphyseal breadths, and in particular those of the elbow and knee joints, should be selected for focus in the determination of sex. In mixed graves where only well-preserved long bones remain, the humerus or tibia might be used in determining sex better than by using the ulna or femur.

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