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THE USE OF BONE WEIGHT FOR HUMAN IDENTIFICATION

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FOUR FIGURES

INTRODUCTION

Within the past few years physical anthropologists have become increasingly involved in the problems of human identification. Techniques have been applied to individuals which were originally devised for the description of groups, and while these are the best available, they do not provide the desired certainty for the identification of an individual. Recent work on identification criteria has concentrated on improving the existing methods. Trotter and Gleser ('52) have published new material on stature estimation, and Stewart and Trotter ('54) have put together all the important previous material on aging. Currently, research is underway to improve techniques for age estimation (McKern and Stewart, '57).

There is obviously a need not only for the improvement of older methods, but also for the establishment of new criteria.

A measurement of the living weight of a man is a potentially important piece of information available to the identification worker; however, present techniques have not permitted any statistical use of these data. Anthropologists have felt that the size and weight of the skeleton were a good guide to the living weight of the individual, but no quantification was attempted. Ingalls ('31) reported that bone weights fluctuated in the same direction as body weight with aging. However, he does not present individual data and draws his conclusions

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from cross-sectional group fluctuations. More recently Trotter ('54) established that dry skeletal weight is related to living stature, but the correlation is not high enough to warrant stature prediction on a bone-weight basis. Physiologists have claimed that bone mineral constitutes 5 to 7% of the fat free weight of the body (Behnke et al., '42). In all cases it is implied that the skeletal weight forms a relatively constant proportion of the normal human body. If the bone does form a consistent segment, it could also act as a convenient guide for predicting the living weight. With this prediction in mind, research was undertaken by Army Graves Registration Service Headquarters, Kokura, Japan on the war dead remains that were being repatriated during "Operation Glory."

PREPARATION AND MEASUREMENTS

For the purposes of this study only remains which had been completely skeletonized by natural factors were used. Care was also taken to select only complete skeletons from which the fat in the bone had leached out; bones were not defatted by chemical or mechanical means. Moisture was removed from the skeleton by drying at a temperature of 150°F until there was less than a 10 gm per hour loss. This usually required 12 to 15 hours of drying. The complete skeleton and its segmental parts were weighed and measured before the bones had reabsorbed the atmospheric moisture at room temperature.

Measurements were made on 125 skeletons. Dry weight of the total skeleton, the skull, and the following right and left bones and bone combinations was obtained: femur, tibia plus fibula, humerus, radius plus ulna, innominate, and clavicle. Maximum lengths were taken of the long bones using an osteometric board. Volume measurements of the right clavicle and long bones were made by water displacement in specially constructed tanks. Two different containers were used. One tank 61 cm high and 10.0 by 12.6 cm in cross section was used for measuring femur and tibia plus fibula volume. The other

bones were measured in a cylinder 51 cm high and 9.4 cm in diameter. The meniscal change in an attached glass tube of 4 mm inside diameter was measured in millimeters and converted to cubic centimeters of water. These values were corrected for water absorption in the bone by weighing the bone before and after immersion. Measurement by other volumetric techniques was not attempted.

The identification of the individuals studied was not available to the investigators at the time of measurement, and the sample was not selected for any biological criteria other than condition and completeness. Individual's specimens on whom identification was not established by the Army Graves

TABLE 1

Demographic data on the skeletal population

		AGE			LIVING WEIGHT		STATURE	
		N	Mean	S.D.	Mean	S.D.	Mean	S.D.
			yr.		*lb.*		*in.*	
Killed in action	Whites	15	20.3	1.3	140.3	16.4	68.2	2.0
	Negroes	1	18.2	—	176.0	—	67.2	—
Died as POWS	Whites	80	25.4	6.0	152.7	26.3	68.2	2.6
	Negroes	19	26.5	3.4	145.5	14.9	67.9	2.6

Registration Services were rejected from the series before statistical analysis. The demographic information presented in table 1 was obtained from personnel files at the Office of the Quartermaster General.

RESULTS

Nutritional and racial factors in bone weight

The skeletal material used in the study came from many different cemeteries in North Korea, and it is possible that differing soil conditions could lead to differential leaching and decaying processes. The internal consistency of the sample was investigated, but only one significant factor was uncovered: the soldiers killed in action and interred by Americans were wrapped in canvas, while those who died in POW

camps were buried without any cover. Consequently, the skeletons of the men killed in action still contained appreciable fat and could not be used for this analysis without defatting.

The exclusive use of the remains of men who died in POW camps made it necessary to consider the possible effects of nutritional deficiency on bone weight. Two methods were used to investigate this problem. First, the skeletal weight

TABLE 2

Negro-White differences in bone measurements

	WHITE		NEGRO		NEGRO-WHITE	"t"
	Mean	S.D.	Mean	S.D.	Mean difference	
	gm		*gm*		*gm*	
Dry weight						
Total skeleton	4290	607	4585	445	295	2.41 [1]
Rt. femur	409	60	420	41	11	.94
Rt. tibia + fibula	299	50	324	36	25	2.38 [1]
Rt. humerus	152	23	166	22	14	2.33 [1]
Rt. radius + ulna	106	16	121	13	15	4.35 [2]
Rt. clavicle	22	5	23	4	1	.76
Rt. innominate	184	34	180	28	—4	—.53
Skull	676	117	740	77	64	2.90 [2]
Volume						
Rt. femur	398	88	410	77	12	.58
Length						
Rt. femur	470	24	476	23	6	1.00
Sample size	80		19			

[1] 5% level of significance = 1.99.
[2] 1% level of significance = 2.63.

of men who were reported to have died from nutritional deficiency diseases was compared to the skeletal weight of those who presumably died from pulmonary disorders. Second, skeletal weights were correlated to the length of time that a man was held prisoner prior to his death. In neither case were the results statistically significant. This is partially explained by the short time the men spent as prisoners of war; the average was only four and one-half months with a

standard deviation of less than two months. While these tests cannot be considered conclusive evidence concerning the effects of nutritional inadequacy on adult bone weight, for the purposes of this study, the men who died from deficiency diseases did not show significant changes in bone weight.

Within the POW war dead group significant racial differences appeared in the bone weights. The Negro skeletons were approximately 7% heavier than the White skeletons, even though the living weight of the Negroes at the time of induction into the Army was 5% (or 7 pounds) lighter than the Whites. An analysis of the differences in individual bones, given in table 2 shows that the difference is concentrated in the extremities and the skull. In contrast, the innominate bone is slightly heavier in the Whites.

The overall skeletal difference in weight as well as the segmental difference required separate racial analyses.

The relationship between living weight and bone measurements

The plots of living weights against total skeletal weights are shown in figures 1 and 2. Although the relationship is closer for the Whites, it can be seen from the figures that the correspondence between these two weights is not high for either Whites or Negroes. The correlation coefficient for the Whites is .544 and for the Negroes .392. In neither case are the values sufficient to make dry skeletal weight an efficient predictor for exact living weight. However, the correspondence found for Whites is close enough to warrant broad classification, that is, a low bone weight may be safely ascribed to an individual of below average weight, and an average skeletal weight belongs to a person who was of near average weight. The top of the scale presents a more complex picture because a very heavy person may have only a moderately heavy skeleton. It appears that whatever relationship exists between total weight and skeletal weight is a function of the correspondence between the bone and the rest of the fat free tissue. Therefore, very obsese individuals have the same

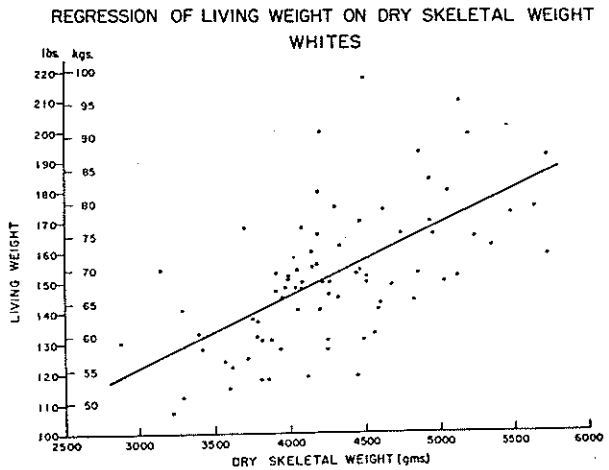

Figure 1

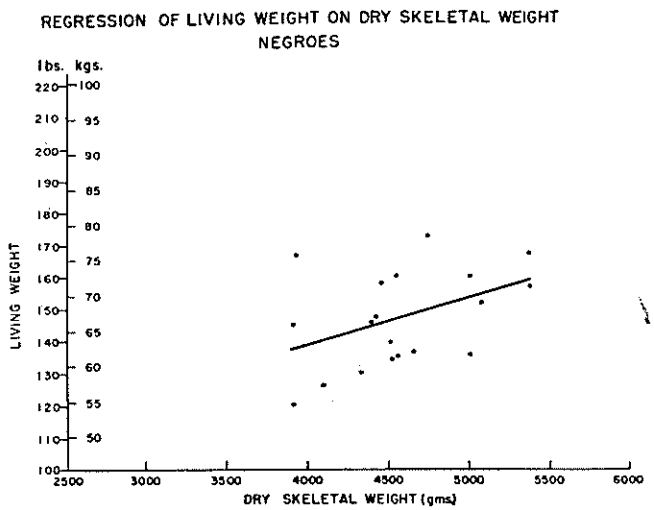

Figure 2

bone weights that would be found for men who weighed as much as a hundred pounds less.

In an effort to simplify the procedures and eliminate the requirement that the total skeleton be present, the relationship between femur measurements (the heaviest single bone in the body) and living weight was investigated. The correlation coefficients are presented in table 3, and the plots are shown in figures 3 and 4.

TABLE 3

The correlation coefficients of bone measurements to living weight

	WHITES r	NEGROES r
Living weight to dry skeletal weight	.544 [2]	.392
Living weight to dry femur weight	.535 [2]	.449 [1]
Living weight to femur volume	.398 [2]	.042
Living weight to femur length	.295 [2]	.085

[1] 5% level of significance = .456.
[2] Significant at the 1% level.

The correlation coefficients of dry femur weight to living weight for the Whites and Negroes are equivalent to those obtained by using the total skeleton, and the use of the femur alone seems well warranted as measurement of the femur alone is simpler than total skeletal weight and can be used even on incomplete skeletons. In the White sample the additional femur measurements of volume and length were also significantly correlated to living weight, but a multiple correlation using all three femur measurements was only .541, which is not substantially better than the value using only femur weight, and requires additional measures. It appears that dry femur weight alone is probably the most efficient predictor available. Table 4 gives the prediction equations which can be used for the prediction of living weight. Separate equations must be used for Negroes and Whites to insure maximum accuracy of prediction.

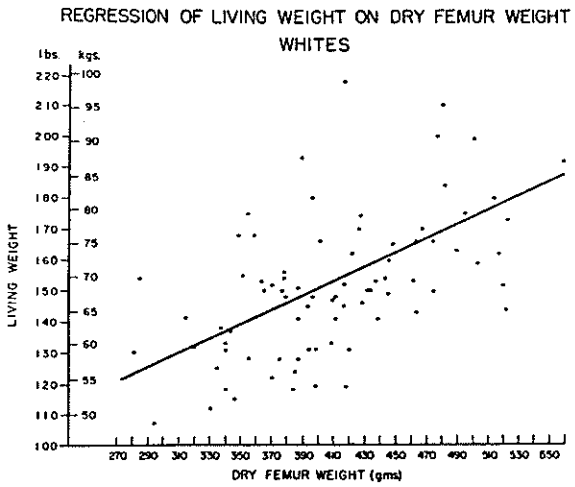

Figure 3

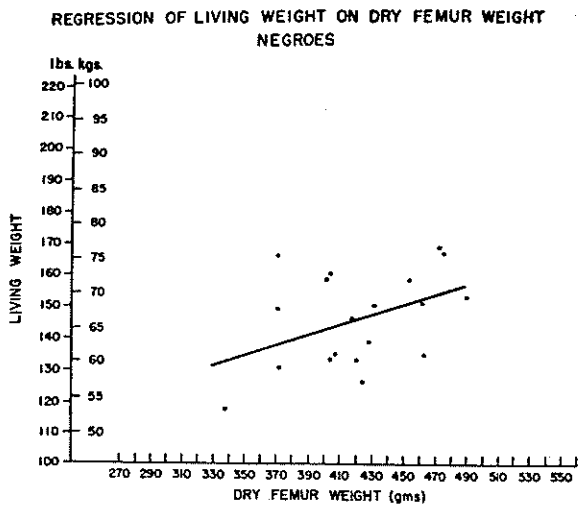

Figure 4

The prediction of bone weights from living weight and stature

In the preceding section the analysis has been directed toward predicting living weight from the skeletal material. A different, but equally valid, approach for associating an unknown skeleton with a specific individual is the prediction of a skeletal characteristic from information concerning the individual while alive. In this case bone weights may be

TABLE 4

Equations for the prediction of living weights from bone weights

Whites	Living weight[1] = .024 (Dry skeletal weight)[1]	+ 50.593 ± 20.1
	Living weight = .233 (Dry femur weight)	+ 57.385 ± 22.2
Negroes	Living weight = .013 (Dry skeletal weight)	+ 85.406 ± 13.7
	Living weight = .163 (Dry femur weight)	+ 76.962 ± 13.3

[1] Living weight in pounds. Bone weight in grams.

TABLE 5

The multiple correlation coefficients and regression equations of stature and weight to dry skeletal weight

	R	REGRESSION
White	.642	Dry skeletal weight[1] = 8.155 living weight[1] + 91.736 stature[1] — 3214.457 ± 462
Negro	.541	Dry skeletal weight = 5.545 living weight + 74.374 stature — 1273.608 ± 376

[1] Dry bone weight in grams. Living weight in pounds. Stature in inches.

predicted from the living stature and weight. The multiple correlation coefficients and regression equations for total skeletal weight from stature and living weight are shown in table 5.

These correlation coefficients are substantially better than those obtained by using the reverse procedure of predicting living weight from bone measurements. As shown by the R values, the application of the same weight and stature criteria gives an even better prediction of femur weight than skeletal

weight. The exact reasons for this further improvement are not obvious, but it may be that the lesser degree of weathering and other post mortem changes in the femur make its weight a more accurate measurement than total skeletal weight. Whatever the reason may be the higher correlations indicate that the femur weight should be used and the more difficult measurement of skeletal weight is not required for implementing this identification technique. Table 6 gives the multiple correlation coefficient values and the regression equations derived from these samples.

TABLE 6

The multiple correlation coefficients and regression equations of stature and weight to dry femur weight

	R	REGRESSION
White	.703	Right femur weight[1] = .650 living weight[1] + 12.314 stature[1] — 530.073 ± 43.1
Negro	.706	Right femur weight = .405 living weight + 10.001 stature — 317.912 ± 29.2

[1] Femur weight in grams. Living weight in pounds. Stature in inches.

The interrelationship of the skeletal components

When commingled remains are found they must be separated into skeletons representing the individuals present in the common grave. With present techniques the anthropologist must depend on the subjective criteria of morphology, color, and component articulation. The dry bone weight offers an additional and objective criterion for segregating the bones into individuals. Table 7 gives the correlation matrices for the skeletal parts, and the prediction formulae for all significant relationships are given in Appendix B. The intercorrelations of the skeletal components are high enough to warrant accurate prediction in many cases. When the correlation is above .8 the actual weight of bone Y should correspond closely with the value predicted from bone X. When the "r" value falls between .7 and .8 a greater difference should be expected. Below a coefficient of .7 large discrepancies may be anticipated.

From the matrices it is apparent that the skull weight is very poorly related to the axial skeletal components and the weights do not offer a practical method for establishing association.

TABLE 7

The intercorrelations of dry bone weights

WHITES N = 80	RIGHT FEMUR	RIGHT (TIBIA AND FIBULA)	RIGHT HUMERUS	RIGHT (RADIUS AND ULNA)	RIGHT CLAVICLE	RIGHT INNOMINATE	SKULL
Total skeletal	.887	.878	.842	.841	.720	.917	.724
Right femur		.906	.739	.771	.601	.829	.464
Right (tibia and fibula)			.762	.793	.602	.767	.480
Right humerus				.851	.659	.777	.459
Right (radius and ulna)					.715	.754	.482
Right clavicle						.634	.508
Right innominate							.549
5% level of significance = .220			1% level of significance = .287				

NEGROES N = 19	RIGHT FEMUR	RIGHT (TIBIA AND FIBULA)	RIGHT HUMERUS	RIGHT (RADIUS AND ULNA)	RIGHT CLAVICLE	RIGHT INNOMINATE	SKULL
Total skeletal	.828	.749	.606	.497	.507	.790	.397
Right femur		.862	.743	.636	.351	.760	.096
Right (tibia and fibula)			.701	.693	.373	.630	.160
Right humerus				.750	.235	.651	—.138
Right (radius and ulna)					.556	.432	.079
Right clavicle						.262	.364
Right innominate							.371
5% level of significance = .456			1% level of significance = .575				

Bone weight intercorrelations are substantially lower for the Negroes. An examination of the methodology and statistical techniques failed to show any reason for this artifact and it must, therefore, be assumed that there is generally less interrelationship between the components of the Negro skeleton than there is in the White skeleton. Nevertheless, the long bone weights can be predicted with some accuracy even for the Negroes.

An additional independent criterion improves the association by reducing the probability of two individual bones having the same values. The femur analysis showed the length to be moderately independent of the weight. As indicated in table 8 the same is true of the other long bones.

Trotter and Gleser ('52) have shown that the long bone lengths are very highly intercorrelated and, since the lengths are moderately independent of the weights, length predictions can be added to weight predictions for a more accurate estimate of association. Trotter's article lists only the prediction equations for long bones from femur length. Thus, at present, length criteria can be applied only when the femur is present and in good condition. A practical example of how to use these criteria is given in Appendix A.

TABLE 8

Correlation coefficients of bone weights to bone lengths

	FEMUR WT. TO FEMUR LGTH. r	TIBIA + FIBULA WT. TO TIBIA LGTH. r	HUMERUS WT. TO HUMERUS LGTH. r	RADIUS + ULNA WT. TO ULNA LGTH. r
Whites N = 71	.427	.553	.340	.600
Negroes N = 19	.504	.647	.457	.816

DISCUSSION AND CONCLUSIONS

The measurement of dry bone weight provides the identification specialist with new information which can be applied to two areas of identification. First, the bones may be associated with an individual by the prediction of dry femur weight from living stature and weight. Second, dry bone weights can be utilized for sorting individuals from commingled remains. However, drying the skeleton for weighing is a lengthy process which requires the use of large drying ovens and requires that the remains be skeletonized when obtained. Because many remains are not skeletonized when brought to the specialist, the prediction of dry femur weight from living stature and body weight cannot be used as a routine identification technique. Commingled remains are

generally skeletonized, and the technique of associating bones by weights can be implemented. The high degree of reliability inherent in the method makes it even more desirable as a standard procedure. Therefore, while the associations of femur weight with living weight and stature cannot at present be recommended as a standard tool, the segregating of commingled remains by bone weight could be used as a routine technique.

Stature reconstruction and age estimation from skeletal material has provided much interesting information about ancient populations. Unfortunately, the reconstruction of living weights from the skeletal weights of these populations does not appear to be a feasible undertaking. Cook and Heizer ('51 and '52) have shown that both the mineral and organic components of bone undergo radical change when buried in the soil for any great period of time. Therefore, while bone weights probably do not alter to any important extent in 5 or 10 years of burial (as is frequently encountered in forensic medico-legal identification work), they do alter after the many centuries involved in most archaeological specimens. Cook also found these changes to be highly individualistic to the site, making it impossible to even reconstruct the weight of the freshly de-fatted bone according to age. Unless the worker has the material and the patience to investigate the rate and nature of bone change for each given site, bone weights appear to have little utility in archaeological studies.

Throughout this report the standard errors of estimate of regression equations have been included for the guidance of the investigator in deciding how far individually calculated values may diverge from the expected results. However, the standard errors apply only to the samples reported here, so this statistic has two limitations which must be taken into account. First, any future sample will probably differ in some characteristics from the present one, and second, even if future samples were drawn from the same population, such samples will probably not have the same standard errors (Snedecor, '46). For these reasons the investigator should

use the standard error of the regression only as a general guide to divergence and not expect all his results to fall within the exact limits defined in this study.

SUMMARY

The skeletal remains of 125 individuals were dried and weighed to investigate the utility of bone weight for identification and for segregating individuals in group burials. Skeletal components formed differing proportions of total skeletal weight in Whites and Negroes: therefore, the racial groups were analyzed separately. It was found that broad categories of living weight can be predicted from total dry skeletal weight or from the dry right femur weight. However, the reliability of associating bone weights with living measurements can be increased by reversing the procedure, that is, predicting dry right femur weight from living weight and stature. The separate dry bone weights of the skeleton were found to be closely correlated to each other in most cases; in conjunction with length measurements they may be used for a highly reliable method of segregating commingled long bones into individuals. The regression equations and a practical example for segregating individuals are provided in the appendices.

ACKNOWLEDGMENTS

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APPENDIX A

Theoretical examples for applying weight and length in determining bone association

For this example it is assumed that the commingled fat-free bones of 6 White individuals have been found. All of the long bones should first be measured for length. Then they should be dried, as described in the Methods Section, and the individual bones weighed. Since the right femur weight is highly correlated to the other bone weights, it is a logical initial choice. The left femur will be easy to determine as it has an almost identical weight and length. From the right femur the weight of almost any bone belonging to the same individual can be predicted using the formulae presented in Appendix B. For example, if the femur weighed 409 gm, then the associated right humerus should weigh about 152 gm. It is not probable that any of the right humeri found will have exactly the predicted value, but one should fall within plus or minus 40 gm of this value. If more than one or none of the humeri are between these values, then using Trotter's regression equations, length measurement may be applied to determine the associated bone.

The same basic procedure applies to the association of the other long bones, although once two bones have been associated, both can be used for predicting the third. Thus, as each new bone is segregated new criteria are provided. This does not mean that the last associations need utilize all the other bones of the individual as predicting criteria;

such a process would be unwieldy and unnecessary. In general, the investigator should set up his own overall procedure, relying heavily on the prediction equations which are accompanied by high "r" values.

The use of bone weights and lengths in this manner will accurately segregate the major bones into individuals, but it does not solve the difficult problem of segregating the small bones such as ribs, vertebrae, and phalanges. However, the positive segregation of the major bones will provide the worker with a more accurate basis for applying subjective techniques to the rest of the skeleton.

APPENDIX B

Prediction equations for estimating bone association

Dry weight in grams. Equations based on the right side only of paired bones

WHITE

Total skeletal weight =

8.841	Femur	+	670.239	± 278
10.823	(Tibia + Fibula)	+	1036.579	± 288
22.457	Humerus	+	871.137	± 327
32.817	(Radius + Ulna)	+	800.010	± 327
108.992	Clavicle	+	1833.228	± 420
16.197	Innominate	+	1315.164	± 241
3.739	Skull	+	1760.950	± 416

Femur weight =

.089	Total skeleton	+	27.593	± 28
1.121	(Tibia + Fibula)	+	72.505	± 26
1.965	Humerus	+	109.678	± 41
3.022	(Radius + Ulna)	+	88.023	± 39
9.120	Clavicle	+	204.009	± 48
1.470	Innominate	+	139.354	± 34
.240	Skull	+	246.713	± 54

Tibia + Fibula weight =

.071	Total skeleton	−	5.292	± 23
.733	Femur	+	.572	± 21
1.650	Humerus	+	49.532	± 32
2.512	(Radius + Ulna)	+	33.443	± 30
7.415	Clavicle	+	133.187	± 39
1.100	Innominate	+	98.584	± 31
.201	Skull	+	164.481	± 43

Humerus weight =

.932	Total skeleton	+	16.634	± 12
.278	Femur	+	38.482	± 15
.352	(Tibia + Fibula)	+	46.336	± 15
1.250	(Radius + Ulna)	+	19.021	± 12
3.765	Clavicle	+	67.482	± 17
.515	Innominate	+	57.576	± 14
.089	Skull	+	92.025	± 20

NEGRO

Total skeletal weight =

8.988	Femur	+	807.686	± 251
9.652	(Tibia + Fibula)	+	1468.833	± 296
12.472	Humerus	+	2529.405	± 355
16.853	(Radius + Ulna)	+	2576.237	± 388
56.457	Clavicle	+	3280.862	± 385
12.678	Innominate	+	2306.559	± 274
	No significant correlation to Skull			

Femur weight =

.076	Total skeleton	+	70.915	± 23
1.023	(Tibia + Fibula)	+	89.930	± 21
1.407	Humerus	+	188.383	± 28
1.988	(Radius + Ulna)	+	183.385	± 32
	No significant correlation to Clavicle			
1.123	Innominate	+	218.453	± 27
	No significant correlation to Skull			

Tibia + Fibula weight =

.058	Total skeleton	+	56.488	± 23
.726	Femur	+	17.745	± 18
1.118	Humerus	+	138.634	± 25
1.824	(Radius + Ulna)	+	105.431	± 25
	No significant correlation to Clavicle			
.785	Innominate	+	181.783	± 27
	No significant correlation to Skull			

Humerus weight =

.029	Total skeleton	+	29.575	± 17
.392	Femur	+	.078	± 15
.439	(Tibia + Fibula)	+	23.091	± 16
1.237	(Radius + Ulna)	+	17.367	± 14
	No significant correlation to Clavicle			
.508	Innominate	+	73.608	± 17
	No significant correlation to Skull			

APPENDIX B (*Continued*)

WHITE					NEGRO				
Radius + Ulna weight =					Radius + Ulna weight =				
.022	Total skeleton	+	14.109	± 8	.015	Total skeleton	+	52.265	± 11
.197	Femur	+	25.691	± 10	.203	Femur	+	33.718	± 10
.250	(Tibia + Fibula)	+	31.077	± 9	.263	(Tibia + Fibula)	+	34.257	± 9
.580	Humerus	+	18.262	± 8	.454	Humerus	+	44.323	± 9
2.768	Clavicle	+	43.976	± 11	1.824	Clavicle	+	77.057	± 11
.341	Innominate	+	43.694	± 10		No significant correlation to Innominate			
.064	Skull	+	63.254	± 14		No significant correlation to Skull			
Clavicle weight =					Clavicle weight =				
.005	Total skeleton	+	1.969	± 3	.004	Total skeleton	+	2.471	± 3
.040	Femur	+	6.348	± 3		No significant correlation to Femur			
.049	(Tibia + Fibula)	+	7.881	± 3		No significant correlation to (Tibia + Fibula)			
.115	Humerus	+	4.966	± 3		No significant correlation to Humerus			
.184	(Radius + Ulna)	+	2.937	± 3	.169	(Radius + Ulna)	+	2.911	± 3
.074	Innominate	+	9.026	± 3		No significant correlation to Innominate			
.017	Skull	+	10.864	± 3		No significant correlation to Skull			
Innominate weight =					Innominate weight =				
.052	Total skeleton	—	38.985	± 14	.049	Total skeleton	—	45.861	± 17
.468	Femur	—	7.774	± 19	.514	Femur	—	36.264	± 18
.535	(Tibia + Fibula)	+	22.849	± 22	.506	(Tibia + Fibula)	+	16.255	± 22
1.174	Humerus	+	5.053	± 22	.834	Humerus	+	42.324	± 21
1.665	(Radius + Ulna)	+	6.630	± 22		No significant correlation to (Radius + Ulna)			
5.442	Clavicle	+	60.784	± 27		No significant correlation to Clavicle			
.160	Skull	+	75.231	± 29		No significant correlation to Skull			
Skull weight =					Skull weight =				
.140	Total skeleton	+	74.936	± 81		No significant correlation to total skeleton			
.896	Femur	+	309.714	± 103		No significant correlation to Femur			
1.146	(Tibia + Fibula)	+	331.875	± 102		No significant correlation to (Tibia + Fibula)			
2.368	Humerus	+	315.520	± 104		No significant correlation to Humerus			
3.640	(Radius + Ulna)	+	289.313	± 102		No significant correlation to (Radius + Ulna)			
14.865	Clavicle	+	341.674	± 101		No significant correlation to Clavicle			
1.877	Innominate	+	331.657	± 98		No significant correlation to Innominate			