ESTIMATION OF STATURE FROM LONG BONES OF AMERICAN WHITES AND NEGROES [1,2]

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FOUR FIGURES

The estimation of stature from length of long bones of the free limbs is often an important contribution to the identification of unknown human remains. The need for identification was realized, perhaps more keenly than ever before in the history of mankind, during the United States Repatriation Program. This program was established by an Act of Congress in 1944. It included the identification (when possible) of unknown war casualties and was assigned to the American Graves Registration Service under Quartermaster Corps. Identification Laboratories were established in suitable parts of the world and the aid of physical anthropologists was enlisted.

Interest in stature estimation from long bones is not new but the number of actual investigations on the subject is relatively few. The most significant report in the last century was that by Rollet in 1888. He measured stature and lengths of the long bones of 50 male and 50 female French cadavers ranging in age from 24 to 99 years and presented all pertinent data including not only the methods of measurement but also the individual measurements and the resultant tables for stature estimation. Stature measurements were taken "generally in the week which followed death" with the cadaver lying on a graduated stretcher. The soft parts were then dissected away

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from the long bones which were measured on the osteometric board of Broca in the "fresh state" without having gone through maceration. A "certain number of the bones" were remeasured 8 or 10 months later in the "dry state" and it was determined that they had lost in general 2 mm of their length. Thus, when stature is to be estimated from the length of "dry" bones it has been the practice to add 2 mm to the measured length of each bone before application of Rollet's tables. The greatest length of the humerus, radius, ulna and fibula; both greatest and bicondylar lengths of the femur; and the distance from the two condyles of the head (with the intercondyloid eminence in the opening of the board) to the extremity of the medial malleolus of the tibia were taken. The tables present the average length of each of the 6 long limb bones of each side of the body for a given range of stature.

The raw data of Rollet served as a basis for application of different methods by Manouvrier (1892 and 1893) and by Pearson (1899). Manouvrier excluded those subjects of 60 years of age and over, 26 males and 25 females. He stated that due to the effect of "old age" on the length of the trunk they had lost 3 cm of their maximum stature. From data on the remaining 49 subjects (24 males and 25 females) he derived tables of average stature corresponding to given long bone lengths. In other words, Manouvrier determined the average stature of those individuals who presented the same lengths for a given long bone, whereas Rollet determined the average length of a given long bone from those who presented the same stature. The values obtained by these two methods are not interchangeable. Manouvrier also indicated that 2 cm should be subtracted from statures obtained by means of his tables in estimating stature of the living.

Pearson applied stature regression formulae utilizing all of Rollet's cases, but limiting long bone lengths to those of the right side unless the right bone was missing in which cases he used the left. He was aware of the wide age range but included all in calculating the constants noting that 50 cases are hardly sufficient for this method of treating data. He also reasoned that, since there were as many old individuals with a stature above as below the median stature, "whatever shrinkage may be due to old age it is not of a very marked character in these data or largely disappears when a body is measured after death on a flat table." The mean stature of the 26 males over 59 years of age was only 1.77 cm less than the mean stature of the 24 males under 60 years of age; the older group of females presented a mean stature of only .04 cm less than the younger group. It has been noted elsewhere (Trotter and Gleser, '51a) that Pearson failed to take cognizance of the greater long bone length in the older group of females than in the younger group and that the older group, therefore, had been taller individuals in their younger years than the stature measurements after death indicated. Pearson made a most valuable contribution to the problem of reconstruction of stature but emphasized that his formulae and curves must not be taken as final, that they merely represent the most probable conclusions which could be drawn from the data at his disposal. He hoped for a wider range of facts, more refined analysis, experiment and observation. In the course of his discussion he stated that "the extension of the stature regression formulae from one local race — say, modern French — to other races — say palaeolithic man — must be made with very great caution" and "stature is quite as marked a racial character as cephalic index."

In 1929 Stevenson accumulated data on a contemporary group of 48 Northern Chinese male cadavers (no ages given) according to methods which were the same as those applied by Rollet. He calculated stature regression formulae which he believed were comparable in all respects to Pearson's formulae for the French and then applied the formulae of each race to the other. The result was a failure of the formulae of one race to give satisfactory prediction results for the second. He emphasized the need of additional data in the form of similar series of regression formulae based on comparable data from other races. Pearson was the editor of the journal in which Stevenson's report was published and thus had the opportunity to add a note to Stevenson's paper. He suggested that there should be some hesitation in accepting all the conclusions but stated frankly that he was prepared to admit that better results from regression formulae will be obtained by applying a formula peculiar to a race itself than by applying a formula arising from a second race.

Breitinger ('37) approached the problem with the statistical methods introduced by Pearson but his data were from living subjects. He pointed out that cadaver material is ill-suited since it mostly represents a certain selection of the population according to age, socio-economic status and geographical distribution; and that stature measurements of cadavers are encumbered with greater errors than stature measurements of the living. His subjects comprised 2400 German males of which 1400 were participants in an athletic meet in Munich in 1923 and 1000 were students in 1925–26. The average age was reported to be about 26 years. Measurements of pertinent divisions of the limbs were taken between certain bony prominences and thus were not as accurate as measurements derived directly from the bones themselves.

Telkkä ('50) presented a chronological review of the literature in addition to his own results based on 154 Finnish cadavers, 115 males and 39 females. The average age of the males was 42.3 years and of the females 50.4 years. The stature was measured on the "prostrate" corpse and the bones were measured after maceration and drying. The skeletons had not all been preserved intact and thus the number of bones of a kind available for measurement was somewhat smaller than the number of subjects. The statistical treatment comprised correlation and regression coefficients between stature and bone measurements.

The United States' program for the return from foreign territory of the remains of World War II deceased made possible the measurements of long limb bones of American military personnel. Such measurements on individuals whose identity had never been lost will contribute to the improvement of identification criteria and thereby help in establishing the identity of unknown remains. The records taken at the time of induction provided the stature measurements. Thus, for the purpose of evolving formulae for stature estimates of American White and Negro males from long bone lengths the desired combination of records was for the first time procurable, viz., the stature measured during life and bones at hand for measurement after death. In addition to the advantage of having living stature measurements of the same individuals whose long bones are measured, it should be noted that these subjects embrace not only a younger age span than cadaver series are known to do, but also a broader and more representative cross-section of the American population. Furthermore, it has been suggested repeatedly that formulae are most accurate when derived from an extensive number of subjects and are applied most suitably to the population from which they were derived. This report will present formulae for estimation of stature from long bone lengths based on American White and Negro military personnel.

In 1948 Stewart wrote "Someone should work up the extensive records of cadaver stature and bone lengths assembled at Western Reserve University and Washington University." Dupertuis and Hadden ('51) at Western Reserve University have responded by their analysis of "groups of 100 male and 100 female American Whites and an equal number of both sexes of Negroes from the Todd Osteological Collection." Stature measurements of these cadavers had been taken by Todd and Lindala ('28). The subjects were secured in the upright position by means which insured that the heels were fairly planted on the floor. Dupertuis and Hadden considered this stature measurement of cadavers to be equivalent to living stature. Their calculations of the regression formulae were based on the values of the bones of the right side only.

In further answer to Stewart the present report includes a study of evidence available in the Terry Anatomical Collection. This material has already served in a study of the effects of ageing on stature (Trotter and Gleser, '51a), a parameter which has not been considered, heretofore, in relation to stature estimation. By making appropriate allowances for the difference in age, it has been ascertained that these data for males and those from the military personnel yield essentially the same formulae. In addition, the Terry Collection supplies data from which equations for estimation of stature from length of long bones can be determined for the females of both races.

MATERIAL

The military personnel were drawn from American World War II casualties in the Pacific zone. The remains were brought by the American Graves Registration Service to Hawaii for preparation for final burial at which time the long bones were measured. Their remains had been skeletonized by natural processes during the temporary burials and the bones were clean and dry. All studied were American citizens of the male sex who had been born in the United States. Stature measurements had been recorded at the time of induction into military service.

The Terry Skeletal Collection is composed of complete skeletons of American White and Negro cadavers which had been assigned to the medical school for scientific study. The collection is well documented with respect to race, sex and age. Its constitution is similar to that of the Todd Skeletal Collection insofar as racial admixture of Whites and Negroes is concerned — even though there is not complete agreement on the question of extent of hybridization of the American Negro (Herskovits, '28; Terry, '29, '32; Todd and Lindala, '28).

The distribution of subjects contributing to this study from both military personnel and the Terry Collection is shown in table 1 according to source, race, sex and age. The age recorded for the military personnel is that at the time of induction into service when stature was measured; age for the Terry Collection is that at the time of death.

The right and left long bones of both upper and lower free limbs were considered, viz., humerus, radius, ulna, femur, tibia and fibula. When all twelve were present the list is referred to as complete; when one or more was absent, as incomplete.

The subjects of the Terry Collection were all complete and of the military personnel, 568 White males and 55 Negro males were complete. The incomplete group was classified under two categories: (a) absence of ulna(e) and/or fibula(e); and (b) miscellaneous absences.

The ages of the great majority of military personnel are in the late teens and early twenties. During this period the amount of increase in stature is small; and soon thereafter

TABLE 1

Distribution of subjects according to source, race, sex and age

AGE	MILITARY PERSONNEL		TERRY COLLECTION			
	White Male	Negro Male	White		Negro	
			Male	Female	Male	Female
17	46	3				
18	210	9				
19	105	7				2
20–29	676	52	1	1	46	31
30–39	76	14	11	8	66	38
40–49	2		37	3	69	36
50–59			53	8	76	26
60–69			86	16	65	16
70–79			52	18	29	19
80–89			15	9	9	8
90–99						1
Total	1,115	85	255	63	360	177

the maximum stature is reached. In order to utilize the data most effectively it was necessary to determine at how young an age stature does not differ significantly from the maximum stature. A decision to include all subjects of 18 years and over was based on findings which indicate that the amount of increase in stature after 18 years is insignificant. Randall ('49) in a study of age changes in 17,341 Army males, ranging in age from 17 to 26 wrote on the subject of stature,

> "Even though the mean values indicate a maximum attained at age 24, there is no statistically significant change after age 18. Consequently, evidence is strong that the American White male attains his adult stature, as an average, in the 18th year."

The military series under present consideration support Randall's evidence. The mean statures according to race and age are presented in table 2. Actually, in the White group the average stature of the 17 year olds is greater than that of the 18 and 19 year old subjects, no one of which shows a statistically significant difference from the average stature of the total

TABLE 2

Mean stature (cm) and length of period (years) between stature measurement and death of military personnel according to age

AGE	WHITE MALES			AGE	NEGRO MALES		
	No.	Stature	Period		No.	Stature	Period
17 [1]	46	174.85	1.95	17	3	169.00	2.58
18	210	174.05	1.96	18	9	174.00	2.30
19	105	174.40	2.30	19–20	12	171.50	1.66
20	121	175.43	2.32				
21	94	175.14	2.47	21–22	21	172.29	2.84
22	95	174.32	2.41				
23	67	174.43	2.22	23–28	22	171.27	2.47
24	71	173.14	2.44				
25	73	174.15	1.81				
26	67	173.45	2.29				
27	31	172.52	2.50				
28	31	174.74	2.28				
29	26	173.27	2.49	29–37	18	173.06	2.36
30	26	173.23	2.61				
31–33	31	171.03	1.94				
34–48	21	172.27	2.82				
Total	1,115	174.23	2.25	Total	85	172.14	2.41

[1] A given year of age indicates a period from one birthday until the next. Periods of more than one year were made arbitrarily in instances where the frequency was small.

group. In the Negro group the number of subjects in these age categories is too small to justify conclusions. For both races, only those subjects who were 18 years and over at the time stature was measured are included in the statistical analysis. The subjects who were excluded on account of their youth consist of 46 White males (23 complete, 10 with absence of ulna(e) and/or fibula(e), and 13 with miscellaneous absences) and three Negro males (one complete, two with miscellaneous absences).

The average length of the period which elapsed between the measurements of stature and death is also summarized in table 2. It may be seen that the lapse of time is relatively short — slightly more than two years, on the average. It is only before maximum stature is reached that a disparity between times of measurement of stature and of long bones could introduce an error.

The Terry Collection subjects are all over 18 years of age but the range extends into the tenth decade and thereby introduces the need of correction for loss of stature with age increment after maturity. The correction formula is available (Trotter and Gleser, '51a) and thus stature measurements derived from these older subjects can be made comparable to those of the military personnel.

METHOD

The stature measurements of the military personnel were made under the direction of either the War Department or the Navy, thereby involving not only many different stations but many different observers. It is desirable to have all measurements of a given variable made by the same individual in order to keep the observational error at a minimum. Errors incurred by many different observers tend to reduce the correlation between variables but this effect is relatively small when sufficiently large series of observations are obtained. All observations were recorded in inches and have been transformed to the nearest centimeter. Numerous attempts have been made to learn the directions for taking height with the following results: in Mobilization Regulations, War Department, October 15, 1942, there was found:

> "10. Directions for taking height. Use a board at least 2 inches wide by 80 inches long, placed vertically, and carefully graduated to ¼ inch between 58 inches from the floor and the top end. Obtain the height by placing vertically, in firm contact with the top of the head, against the measuring rod an accurately square board of about 6 by 6 by 2

> inches, best permanently attached to graduated board by a long cord. The individual should stand erect with back to the graduated board, eyes straight to the front."

In another set of Mobilization Regulations dated 19 April 1944 essentially the same directions were given and in addition the following sentence:
"The shoes should be removed when the height is taken." An extract from Manual of the Medical Department, Revised 1945, United States Navy indicates:
"A minimum height of 60 inches without shoes is required." It has been assumed, therefore, that the statures listed on the records for all military personnel were taken with the subject in the erect position and with shoes removed. The stature acceptable for induction varied slightly among the service divisions with the extremes from 60 inches to 78 inches (152 cm–198 cm) inclusive.

The stature measurements of the Terry Collection subjects were made when the cadavers were brought to the Medical School. A specially constructed vertical measuring panel with a foot board was utilized.

> "With careful attention to the several details involved in posing and fixing the cadaver on the panel, the characteristic features of the standing posture can be reproduced: ankles bent, knees and hips extended, lumbar curve produced, shoulders squared and arms hanging at the sides, the face front and eye-ear plane horizontal." (Terry, '40.)

A metric scale was attached to the measuring panel. Each subject was photographed in anterior and lateral views. The photographs record the actual position of the cadaver and make feasible a correction in the stature measurement when, for example, the heels are not flat on the baseboard.

Measurements of length of all 12 long limb bones for Terry Collection subjects, and of as many as were present for military personnel were made by the senior author as follows and recorded to the nearest millimeter:

Humerus. Maximum length. Head was applied to the vertical part of the osteometric board, bone was held by left hand, block was applied horizontally to distal extremity, bone was raised slightly, moved up and down as well as from side to side until maximum length was determined (Hrdlička, '47).

Radius. Maximum length. Taken in same way as that of humerus (Hrdlička).

Ulna. Maximum length. Taken in same way as that of humerus (Hrdlička).

Femur. Bicondylar length. Both condyles were adjusted to the vertical part of the osteometric board and with the bone reposing on the board, the block was applied to the other extremity (Hrdlička).

Maximum length (indicated subsequently as $femur_m$). Medial condyle was applied to the vertical part of the osteometric board and measurement was made in the same way as the maximum length of other bones (Martin, '28).

Tibia. Maximum length (indicated subsequently as $tibia_m$). End of malleolus against vertical wall of the osteometric board, bone resting on its dorsal surface with its long axis parallel with the long axis of the board, block applied to the most prominent part of lateral half of lateral condyle.

Ordinary length. Measured with spreading calipers from the center of the articular surface of the lateral condyle to the center of the inferior articular surface (Krogman, '48).

Fibula. Maximum length. Taken in same way as that of humerus (Hrdlička).

The statistical analyses do not involve new methods. Regression equations introduced into this field by Pearson in 1899 and based on a linear relationship between the variables are proved again to be satisfactory. However, three refinements have been introduced: one, the utilization of stature measured on the living in combination with bone lengths measured after death on the dry skeleton; two, recognition of and adjustment for the effect of ageing on stature; and, three, a test of the validity of the resultant equations by application to a different sample of reasonably large size.

RESULTS AND DISCUSSION

Comparison of lengths of right and left bones. The 545 military White subjects who were 18 years or older and with all long bones present provided the data for comparisons between lengths of right and left bones. The object was to determine any possible difference resulting from utilization of one or the other bone of a given pair in estimation of stature. The complete matrix of intercorrelations is summarized in table 3. There is neither a large nor consistent difference in the amount of correlation for right and left bones of any pair except for the radius in which instance the left bone has a higher correlation with all other bones and with stature than does the right radius. Since the difference in standard deviation for any two corresponding bones is likewise very small there could be very little difference between estimation equations for stature evolved from them. There is, in general, a slight advantage in using the average length of the two bones of a pair when both are present, because of the greater reliability of an average. In addition, equations of estimation based on average values minimize the error of estimate when only one bone of a pair is present, since neither the right nor left member of a pair has a greater likelihood of preservation. Accordingly, it was decided to use the average length of bone pairs in this study.

The mean difference between right minus left bone lengths of a given pair and the standard deviations of these differences are recorded in table 4 for the 545 military White males and also for all available bone pairs of the military Negro males. The differences between the two races are in the same direction for any given bone except the humerus. The differences are all significantly different from zero for the larger sample (Whites), whereas the differences only for radius, ulna, and femur are significant for the smaller sample (Negroes). As has been found previously (Pearson, 1899; Telkkä, '50; Dupertuis and Hadden, '51) these differences are small on the average (the highest being 0.3 cm for the radius of the Negroes) although in some individual pairs they may be as much or more than 0.5 cm. It is impossible to predict the

amount or direction of this difference for any particular pair in a single individual. However, the error could be corrected in an estimation equation by adjusting for the difference between the means. When the equation is based on the average length of both bones only one-half of the indicated difference between the right and left bones should be added or subtracted to the measured length for insertion in the equation. This amounts to less than a millimeter for all excepting the radius and ulna and thus is less than the error of measurement itself.

TABLE 4

Mean differences[1] *(cm) (with standard errors) and standard deviations between lengths of right and left paired bones of military personnel. (The numbers in parentheses indicate the number of subjects involved)*

	WHITE MALES (545)		NEGRO MALES (68–80)	
	Mean diff.	S.D.	Mean diff.	S.D.
Humerus	+ .045 ± .016	.365	— .021 ± .041	.366
Radius	+ .185 ± .023	.510	+ .300 ± .037	.323
Ulna	+ .193 ± .017	.389	+ .252 ± .039	.319
Femur	— .111 ± .018	.404	— .095 ± .045	.405
$Femur_m$	— .058 ± .021	.472	— .043 ± .046	.411
$Tibia_m$	— .055 ± .016	.359	— .054 ± .032	.282
Tibia	— .028 ± .014	.321	— .046 ± .033	.295
Fibula	— .035 ± .015	.326	— .057 ± .047	.388

[1] The difference is expressed as length of right bone minus length of left, thus a + figure signifies a longer right bone and a — figure, a longer left bone.

Even for these two bones it can easily be shown that the resultant error in the estimated stature is less than half a centimeter. It seems impractical and unnecessary, therefore, to make an adjustment when only one bone of a pair is available for stature estimation.

Equations for estimation of stature from a given bone length. For the determination of equations for estimation of stature from long bone lengths, the average length of the paired bones was utilized. Complete matrices of intercorrelations of stature, age, and long bone measurements were computed. In the military White group those cases (165) in which all but the ulna(e) and/or fibula(e) were present were treated separately from the "complete" cases. (Data for the "miscellaneous incomplete" White subjects were not included in these computations.) In the military Negro group all possible bone pairs were included in each correlation with stature because of the small sample. All subjects from the Terry Collection were complete and were utilized for obtaining correlations and regression equations.

The means (with standard errors) and the standard deviations of the distribution of measurements for each group are presented in table 5. For the Terry Collection the stature is that of the cadaver whereas for the military samples the stature is that of the living, thus the averages are not directly comparable. However, all bones measured were without cartilage and dry and hence are directly comparable.

The differences between the mean measurements and between the standard deviations for the two groups of military White males are insignificant, indicating as may have been expected, uniformity of the complete and incomplete groups with respect to age, stature and average length of bone pairs.

Every measurement for White males is significantly smaller for the Terry Collection subjects than for military personnel. However, the standard deviations of these measurements for the two sources are in agreement within the limits of sampling error, excepting that of stature which is significantly greater for the Terry Collection subjects. It is suggested that part of the variance in cadaver stature has resulted from post-mortem changes which are differentially produced. In this connection it is noted that the standard deviation of stature measurements is much larger for Negro males of the Terry Collection than for Negroes of military origin. This large difference is partially due to a difference in general variability between the two samples since the Negroes of the Terry Collection have a significantly larger standard deviation for each bone measurement than do the military Negroes or any of the White samples. It is interesting also, that the Negro samples from the two sources have comparable measurements of upper limb bones, but that the measurements of the lower limb bones differ sig-

TABLE 5

Mean (with standard error) and standard deviation of age (years), stature[1] and long bone measurements (cm) according to race, sex and source of data

White males

	MILITARY COMPLETE (545)		MILITARY INCOMPLETE (165)		TERRY COLLECTION (255)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Age	23.14 ± .18	4.31	22.65 ± .35	4.46	61.66 ± .77	12.25
Stature	173.899 ± .284	6.626	174.442 ± .476	6.091	170.392 ± .461	7.343
Humerus	33.618 ± .072	1.672	33.678 ± .124	1.582	32.998 ± .112	1.787
Radius	25.151 ± .055	1.280	25.099 ± .103	1.316	24.403 ± .084	1.334
Ulna	27.035 ± .055	1.283			26.218 ± .088	1.402
Femur	46.908 ± .099	2.306	47.179 ± .187	2.391	45.415 ± .151	2.411
$Femur_m$	47.261 ± .100	2.346	47.525 ± .188	2.410	45.660 ± .154	2.447
$Tibia_m$	37.826 ± .093	2.179	37.991 ± .181	2.316	36.374 ± .136	2.170
Tibia	36.848 ± .091	2.113	37.059 ± .180	2.307	35.345 ± .134	2.139
Fibula	38.135 ± .089	2.084			36.782 ± .132	2.103

Negro males

	MILITARY (54)		TERRY COLLECTION (360)	
	Mean	S.D.	Mean	S.D.
Age	25.07 ± .68	4.98	49.46 ± .82	15.51
Stature	172.111 ± .843	6.139	172.729 ± .412	7.807
Humerus	33.793 ± .184	1.337	33.777 ± .099	1.883
Radius	26.568 ± .170	1.240	26.322 ± .084	1.597
Ulna	28.509 ± .182	1.323	28.164 ± .086	1.623
Femur	47.930 ± .307	2.234	47.073 ± .153	2.903
$Femur_m$	48.337 ± .310	2.256	47.424 ± .157	2.969
$Tibia_m$	39.554 ± .316	2.298	38.721 ± .134	2.533
Tibia	38.606 ± .322	2.344	37.667 ± .131	2.486
Fibula	39.763 ± .315	2.295	38.950 ± .130	2.456

Females (Terry Collection)

	WHITE (63)		NEGRO (177)	
	Mean	S.D.	Mean	S.D.
Age	63.93 ± 2.02	16.07	47.21 ± 1.55	17.64
Stature	160.682 ± .946	7.508	160.892 ± .574	6.534
Humerus	30.430 ± .218	1.728	30.764 ± .139	1.578
Radius	22.211 ± .156	1.240	23.602 ± .130	1.477
Ulna	23.994 ± .173	1.372	25.390 ± .115	1.305
Femur	42.654 ± .315	2.503	43.273 ± .205	2.335
$Femur_m$	42.959 ± .319	2.531	43.712 ± .210	2.391
$Tibia_m$	34.029 ± .271	2.151	35.415 ± .188	2.135
Tibia	33.181 ± .263	2.091	34.538 ± .184	2.098
Fibula	34.335 ± .270	2.143	35.549 ± .184	2.099

[1] Stature indicates measurement of the living for military personnel and of the cadaver for the Terry Collection subjects.

nificantly, the Negro sample from the Terry Collection having the shorter bones.

The two female samples from the Terry Collection, which are directly comparable with regard to stature, differ mainly in the lengths of the bones of the forearm and leg (radius, ulna, tibia and fibula) although for every bone the Negro female has a longer average length than the White female.

The average age of the samples from the Terry Collection is much older than the age of the samples of military origin and the spread is considerably wider extending into the later decades. The coefficient of correlation of each measurement

TABLE 6

Coefficients of correlation of age with stature and with long bone measurements for the Terry Collection samples, according to sex and race

	MALES		FEMALES	
	White	Negro	White	Negro
Stature	—.09	—.24	—.31	—.20
Humerus	.03	—.08	—.14	—.02
Radius	.00	—.14	—.02	—.07
Ulna	.01	—.12	.06	.05
Femur	—.01	—.11	—.11	—.09
$Femur_m$	—.02	—.12	—.12	—.11
$Tibia_m$	.04	—.15	—.05	—.07
Tibia	.04	—.15	—.08	—.09
Fibula	.04	—.15	—.05	—.09

with age for the Terry Collection samples is presented in table 6. It can be seen that stature and age are negatively correlated. This negative relationship is contributed to by effects on stature of both the secular trend and ageing. For the secular trend it has been shown that the older the individual the less likely he is to have attained as tall a stature as younger individuals living in the same period. And, for ageing it has been shown that the older the individual (after 30 years of age) the greater will have been his loss of stature (Trotter and Gleser, '51a,b). The effect of the secular trend on stature is evidenced by the negative correlation between age and length of most of the bones. After eliminating this effect by a partial correlation technique, the correlation between stature and age was still negative and statistically significant and was found to be homogeneous for the 4 groups amounting to an average rate of decline of .06 cm per year after 30 years of age (see earlier study). This indicates that the additive constant of an equation for estimation of stature from long bone lengths would vary according to the age of the individual. Thus, a more accurate estimation of stature can be made by including in the calculation an adjustment for the effect of ageing.

The coefficients of correlation between stature and each of the long bone lengths for the several samples of White and Negro subjects are presented in table 7. For the Terry Collection samples the partial correlations of stature with bone length, when age is held statistically constant, are also indicated in parentheses. The standard errors of the correlation coefficients are included to permit determination of significant differences between the corresponding correlations in different samples by inspection. The correlations between stature and long bone lengths for the two military White samples differ only to an extent which might be expected from sampling fluctuations. Since the differences in the means and standard errors of each measurement were insignificant also, it can be concluded that these two samples are drawn from the same population and that equations for estimation of stature from their long bones would not differ significantly.

The two military samples of White males (710 subjects) were, therefore, combined and the means, standard deviations, and correlation coefficients were computed for the total sample using as many data as were available for the ulna and fibula (table 8). (Data for the ulna and fibula were included from the 165 "incomplete" cases when these bone pairs were present.) The differences in correlations of stature and long bone lengths between the military and the Terry Collection White samples are not significant (see tables 7 and 8). The correlations of the latter group are all somewhat lower, especially those for

TABLE 7

Coefficients of correlation (with standard errors) between stature and long bone measurements according to race, sex, and source. Partial correlations when age is held statistically constant are also shown in parentheses for the Terry Collection subjects

	White			
	MALE			FEMALE
	Military personnel			
	Complete (545)	Incomplete (165)	Terry Collection (255)	Terry Collection (63)
Humerus	.790 ± .016	.754 ± .034	.751 ± .027 (.757)	.802 ± .045 (.806)
Radius	.756 ± .018	.732 ± .036	.730 ± .029 (.732)	.789 ± .048 (.823)
Ulna	.755 ± .018		.726 ± .030 (.731)	.759 ± .053 (.731)
Femur	.869 ± .010	.858 ± .021	.859 ± .016 (.862)	.851 ± .035 (.864)
$Femur_m$	.867 ± .011	.861 ± .020	.861 ± .016 (.863)	.858 ± .033 (.869)
$Tibia_m$	.864 ± .011	.833 ± .024	.818 ± .031 (.826)	.845 ± .036 (.873)
Tibia	.872 ± .010	.837 ± .023	.816 ± .023 (.825)	.841 ± .037 (.861)
Fibula	.865 ± .011		.814 ± .021 (.822)	.851 ± .035 (.879)

	Negro		
	(68–80)	(360)	(177)
Humerus	(79) .716 ± .055	.821 ± .017 (.828)	.748 ± .017 (.759)
Radius	(74) .713 ± .058	.792 ± .020 (.789)	.633 ± .053 (.634)
Ulna	(68) .712 ± .060	.773 ± .021 (.772)	.649 ± .051 (.673)
Femur	(80) .769 ± .046	.817 ± .018 (.820)	.835 ± .027 (.837)
$Femur_m$	(80) .768 ± .046	.818 ± .017 (.818)	.848 ± .025 (.853)
$Tibia_m$	(79) .803 ± .038	.859 ± .014 (.857)	.811 ± .030 (.824)
Tibia	(79) .799 ± .041	.857 ± .014 (.855)	.809 ± .030 (.810)
Fibula	(68) .766 ± .050	.861 ± .014 (.859)	.813 ± .030 (.814)

TABLE 8

Means (standard errors), standard deviations, and coefficients of correlation (with standard errors) of stature and long bone measurements (cm) of military Whites males[1]

	MEAN	S.D.	r
Stature	174.035 ± .244	6.510	
Humerus	33.632 ± .062	1.653	.783 ± .015
Radius	25.139 ± .048	1.287	.748 ± .017
Ulna	27.024 ± .052	1.317	.749 ± .016
Femur	46.971 ± .087	2.328	.865 ± .009
$Femur_m$	47.322 ± .089	2.365	.865 ± .009
$Tibia_m$	37.865 ± .083	2.214	.856 ± .010
Tibia	36.897 ± .082	2.162	.862 ± .010
Fibula	38.153 ± .087	2.095	.863 ± .010

[1] The statistics are based for ulna on 644 cases, for fibula on 580 cases, and for all other values on 710 cases.

the tibia and fibula. The differences in correlations between the Negro males from the two sources (table 7) are also not significant. It may be concluded, therefore, that the two samples are drawn from populations equally correlated with regard to stature and length of long bones. The correlations of stature with long bone lengths for the Terry Collection subjects are, in general, slightly higher when age is held statistically constant (table 7) than when age is allowed to vary. The differences are very slight (as predicted by Pearson) and would have very little effect on the slope of the line of regression for

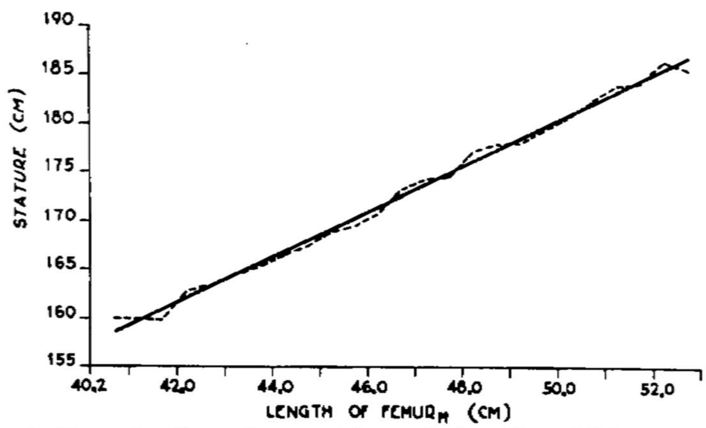

Fig. 1 Regression line and mean statures of 710 military White males grouped according to increments of 0.5 cm in length of femur$_m$.

stature estimation from long bone length. However, the additive constant of the equation, as has already been noted, is different for different age groups.

The possibility was considered that a more accurate estimation of stature from the length of long bones might be obtained by utilizing other than a linear relationship. To test this possibility the mean statures corresponding to increments of 0.5 cm in the length of the femur$_m$ were computed for the 710 military White males. The resulting averages are shown in figure 1 together with the best fitting line of regression. The correlation ratio for this bivariate distribution, arranged in arrays, is .869 as compared to the correlation coefficient of .865.

This difference is not significant statistically. It may be concluded that the relationship between stature and length of femur is linear and that no advantage would be gained in using other than a linear relationship in estimating stature from the $femur_m$ length. Also, there is no reason to doubt that linearity of regression is obtained for stature when estimated from each of the other bones. In point of fact Breitinger proved linearity of regression between stature and length of the radius for his sample. Thus, it has been established empirically that the Pearsonian method of linear regression is justified.

The best fitting linear equation for estimation of stature from the length of each long bone was obtained for each of the samples (table 9). These equations are for estimation of maxi-

TABLE 9

Equations for estimation of stature (cm)[1] (with standard errors) from long bone lengths according to race, sex and source

MALE Military personnel (Living stature)	MALE Terry Collection (Cadaver stature)	FEMALE Terry Collection (Cadaver stature)
White		
3.08 Hum + 70.45 ± 4.05	3.10 Hum + 70.00 ± 4.78	3.36 Hum + 60.47 ± 4.45
3.78 Rad + 79.01 ± 4.32	4.01 Rad + 74.43 ± 4.97	4.74 Rad + 57.43 ± 4.24
3.70 Ulna + 74.05 ± 4.32	3.81 Ulna + 72.40 ± 4.99	4.27 Ulna + 60.26 ± 4.30
2.42 Fem + 60.37 ± 3.27	2.61 Fem + 53.76 ± 3.69	2.48 Fem + 56.93 ± 3.78
2.38 Fem_m + 61.41 ± 3.27	2.58 Fem_m + 54.79 ± 3.69	2.47 Fem_m + 56.60 ± 3.72
2.52 Tib_m + 78.62 ± 3.37	2.79 Tib_m + 70.81 ± 4.13	2.90 Tib_m + 64.03 ± 3.66
2.60 Tib + 78.10 ± 3.30	2.82 Tib + 72.62 ± 4.15	2.95 Tib + 64.83 ± 3.82
2.68 Fib + 71.78 ± 3.29	2.86 Fib + 67.09 ± 4.17	2.93 Fib + 62.11 ± 3.57
Negro		
3.26 Hum + 62.10 ± 4.43	3.35 Hum + 60.75 ± 4.39	3.08 Hum + 67.17 ± 4.25
3.42 Rad + 81.56 ± 4.30	3.78 Rad + 74.40 ± 4.79	2.75 Rad + 97.01 ± 5.05
3.26 Ulna + 79.29 ± 4.42	3.63 Ulna + 71.66 ± 4.96	3.31 Ulna + 77.88 ± 4.83
2.14 Fem + 69.74 ± 3.93	2.15 Fem + 72.69 ± 4.47	2.30 Fem + 62.39 ± 3.58
2.11 Fem_m + 70.35 ± 3.94	2.11 Fem_m + 73.84 ± 4.49	2.28 Fem_m + 62.26 ± 3.41
2.19 Tib_m + 86.02 ± 3.78	2.60 Tib_m + 73.23 ± 4.02	2.45 Tib_m + 75.15 ± 3.70
2.17 Tib + 88.83 ± 3.82	2.64 Tib + 74.46 ± 4.05	2.48 Tib + 76.27 ± 3.83
2.19 Fib + 85.65 ± 4.08	2.68 Fib + 69.51 ± 4.00	2.49 Fib + 73.40 ± 3.80

[1] The stature obtained in each case is that of an individual of 18 to 30 years of age. For the stature of older individuals subtract .06 (age − 30) cm to obtain stature at desired age.

mum stature. An adjustment has been made, where necessary, to offset the effect of ageing on stature. This adjustment for age was not necessary for the military personnel but for the Terry Collection subjects the additive constant was corrected to give the best estimate of maximum stature. When a stature estimate is desired for individuals above 30 years of age, the equation should be modified by subtracting from the estimate the factor, .06 (age — 30) cm. Thus, to obtain the original cadaver stature of each of the Terry Collection samples, the average age of the sample should be inserted in the above expression and the resulting value subtracted from the estimates obtained from the equations as listed in table 9.

It should be emphasized again that the estimation equations for the military personnel provide an estimate of living stature whereas those for the Terry Collection subjects, an estimate of cadaver stature. All equations are to be applied to measurements of dry bones without cartilage. For the military Negro males the equations were computed using the means and standard deviations of stature and long bone length of all individuals for which the particular bone pair was available. Since these values vary somewhat from those listed in table 5 for "complete" military Negro males the detailed statistics are given:

BONE	NO. OF SUBJECTS	BONE LENGTH		STATURE	
		Mean	S.D.	Mean	S.D.
Humerus	79	33.757	1.392	172.151	6.349
Radius	74	26.443	1.279	172.000	6.140
Ulna	68	28.426	1.377	171.956	6.309
Femur	80	47.845	2.209	172.125	6.153
Femur_m	80	48.235	2.246	172.125	6.153
Tibia_m	79	39.485	2.323	172.494	6.342
Tibia	79	38.554	2.331	172.494	6.342
Fibula	68	39.799	2.219	172.809	6.346

In every set of equations, it can be seen that stature has a smaller standard error of estimate when computed from bones of the lower limb than when computed from bones of the upper limb. Thus, the femur, the tibia or the fibula give the best estimates of stature for each group. The two different measurements of the femur and of the tibia in every group give practically identical equations except for the constant term which reflects the difference in average lengths obtained from the two measurements. In general the slopes of the regression equations for stature obtained from the military personnel and from the Terry Collection samples differ only to the extent expected by sampling. It is rather interesting to note, however, that the standard error of estimate is smaller for the military personnel than for the Terry Collection subjects for every comparable equation, indicating again that living stature measurements introduce less error variance.

Multiple regression equations for estimation of stature. When the intercorrelations among several independent variables are known it is possible to determine by multiple regression techniques the best fitting linear equation using any number of these variables in combination. In other words, coefficients can be obtained so that the correlation of $ax_1 + bx_2 + cx_3 + \ldots gx_n + h$ with the dependent variable will be a maximum. This method was introduced by Pearson. It includes, as special cases, the possibility that the variables be given equal weight (in which case the estimates obtained from the different variables may be simply averaged) and also the possibility that all but one of the variables have negligible weights (in which case only one variable need be used for obtaining the best estimation). The actual weights or coefficients obtained for the variables will, of course, vary from sample to sample of a population depending upon the obtained matrix of intercorrelations.

Since the two measurements of the femur and of the tibia give practically identical results in each case for the estimation of stature and since each is almost perfectly correlated with the other there is no advantage in using both measurements of either bone in the determination of multiple equations of estimation. Arbitrarily the measurements indicated as femur_m and tibia_m were retained. The complete matrices of intercorrelations among lengths of the 6 long bones for each of the samples are presented in table 10. In every sample the correlations among the bones are very high indicating that little additional precision can be gained from a multiple regression equation. In particular, the correlations between radius and ulna and between tibia and fibula (both ranging

TABLE 10

Intercorrelations among long bone measurements and stature according to race, sex and source

White males

	MILITARY PERSONNEL (710)[1]						TERRY COLLECTION (255)					
	Hum	Rad	Ulna	Fem_m	Tib_m	Fib	Hum	Rad	Ulna	Fem_m	Tib_m	Fib
Stat	.783	.748	.749	.865	.856	.863	.751	.730	.726	.861	.818	.814
Hum	...	.829	.805	.843	.828	.832	...	.838	.819	.853	.827	.836
Rad	.829	...	.956	.776	.850	.848	.838	...	.970	.799	.863	.873
Ulna	.805	.956	...	.764	.843	.858	.819	.970	...	.796	.852	.868
Fem_m	.843	.776	.764	...	.880	.874	.853	.799	.796	...	.890	.884
Tib_m	.828	.850	.843	.880	...	.970	.827	.863	.852	.890	...	.975
Fib	.832	.848	.858	.874	.970	...	.836	.873	.868	.884	.975	...

Negro males

	MILITARY PERSONNEL (54)						TERRY COLLECTION (360)					
Stat	.701	.649	.643	.758	.813	.793	.821	.792	.773	.818	.859	.861
Hum	...	.726	.676	.763	.759	.749	...	.832	.813	.828	.858	.860
Rad	.726	...	.961	.696	.852	.836	.832	...	.967	.773	.866	.880
Ulna	.676	.961	...	.677	.820	.812	.813	.967	...	.752	.850	.864
Fem_m	.763	.696	.677	...	.849	.831	.828	.773	.752	...	.848	.854
Tib_m	.759	.852	.820	.849	...	.974	.858	.866	.850	.848	...	.980
Fib	.749	.836	.812	.831	.974	...	.860	.880	.864	.854	.980	...

Terry Collection females

	WHITE (63)						NEGRO (177)					
Stat	.802	.789	.759	.858	.845	.851	.748	.633	.649	.848	.811	.813
Hum	...	.833	.794	.875	.834	.837	...	.722	.804	.819	.832	.832
Rad	.833	...	.963	.874	.878	.878	.722	...	.824	.719	.737	.758
Ulna	.794	.963	...	.838	.876	.885	.804	.824	...	.718	.799	.820
Fem_m	.875	.874	.838	...	.905	.910	.819	.719	.718	...	.870	.880
Tib_m	.834	.878	.876	.905	...	.983	.832	.737	.799	.870	...	.980
Fib	.837	.878	.885	.910	.983	...	.832	.758	.820	.880	.980	...

[1] The statistics are based for ulna on 644 cases, for fibula on 580 cases, and for all other values on 710 cases.

above .95 in every group except the Negro females) indicate that there is no advantage in using both bones. Since the ulna and fibula are broken or missing more frequently than the radius and tibia among skeletal remains, they were eliminated from the computation of multiple regression equations.

Multiple regression equations of stature with the lengths of two or more bones in various combinations (humerus, radius, $femur_m$ and $tibia_m$) for each sample are presented in table 11. This table reveals many interesting facts. There is no perceptible increase in accuracy of estimation obtained from using measurements of all 4 bones over that obtained from using two selected bones ($femur_m$ and $tibia_m$). The Negro male groups constitute a possible exception, but, even in these, the gain in correlation is so slight that it could not be expected to hold for a new sample in which these same regression weights are utilized. This is evident in the fact that the radius presents a large negative weight in the military Negro group whereas its weight becomes a small positive value in the comparable Negro group of the Terry Collection. There appears, therefore, to be no advantage in using lengths of all 4 bones simultaneously for estimating stature. Especially should the practice of giving equal weight to all 4 bones, by averaging together the estimations derived from each one, be discouraged. That such a procedure leads to less valid estimates is obvious when the relative weights of the various bone measurements in equation (1) for each group are noted. For the White male and female groups and for the Negro females it is evident that the humerus and radius add little or nothing to the accuracy of estimation when the femur and tibia are available. For all these three groups equally valid estimates are obtained from equations (6 or 7) which involve only the femur and tibia. Also, these are simpler equations to apply than those utilizing lengths of three or 4 bones. Finally, equation (7) utilizing the sum of the lengths of femur and tibia gives a result in every group of nearly, if not, the maximum validity. In no estimation of stature should the humerus and radius be used separately or in conjunction with each other (equation 4) if the

TABLE 11

Multiple regression equations for estimation of stature (cm)[1] (with standard errors) and coefficients of multiple correlation (R) from long bone lengths according to race, sex and source

		R
	Military personnel — White males (living stature)	
(1)	$0.28\,\text{Hum} - 0.02\,\text{Rad} + 1.32\,\text{Fem}_m + 1.16\,\text{Tib}_m + 58.73 \pm 2.99$	.888
(2)	$0.27\,\text{Hum} + 1.32\,\text{Fem}_m + 1.16\,\text{Tib}_m + 58.57 \pm 2.99$	.889
(3)	$0.37\,\text{Hum} + 0.77\,\text{Rad} + 1.84\,\text{Fem}_m + 55.16 \pm 3.15$	.875
(4)	$2.05\,\text{Hum} + 1.60\,\text{Rad} + 64.86 \pm 3.88$	.803
(5)	$0.93\,\text{Hum} + 1.94\,\text{Tib}_m + 69.30 \pm 3.26$	.866
(6)	$1.42\,\text{Fem}_m + 1.24\,\text{Tib}_m + 59.88 \pm 2.99$	.888
(7)	$1.30(\text{Fem}_m + \text{Tib}_m) + 63.29 \pm 2.99$	.888
	Terry Collection — White males (cadaver stature)[2]	
(1)	$0.03\,\text{Hum} + 0.03\,\text{Rad} + 1.82\,\text{Fem}_m + 0.92\,\text{Tib}_m + 54.01 \pm 3.58$	.873
(2)	$0.04\,\text{Hum} + 1.82\,\text{Fem}_m + 0.93\,\text{Tib}_m + 54.04 \pm 3.58$	.873
(3)	$0.03\,\text{Hum} + 0.63\,\text{Rad} + 2.28\,\text{Fem}_m + 51.81 \pm 3.66$	.867
(4)	$1.97\,\text{Hum} + 1.81\,\text{Rad} + 63.10 \pm 4.60$	.780
(5)	$0.85\,\text{Hum} + 2.24\,\text{Tib}_m + 62.76 \pm 3.96$	.842
(6)	$1.84\,\text{Fem}_m + 0.94\,\text{Tib}_m + 54.08 \pm 3.58$	.873
(7)	$1.40(\text{Fem}_m + \text{Tib}_m) + 57.43 \pm 3.69$	.865
	Military personnel — Negro males (living stature)	
(1)	$0.89\,\text{Hum} - 1.01\,\text{Rad} + 0.38\,\text{Fem}_m + 1.92\,\text{Tib}_m + 74.56 \pm 3.38$	.835
(2)	$0.67\,\text{Hum} + 0.49\,\text{Fem}_m + 1.47\,\text{Tib}_m + 67.64 \pm 3.44$	.828
(3)	$1.02\,\text{Hum} + 0.75\,\text{Rad} + 1.32\,\text{Fem}_m + 53.91 \pm 3.78$	.788
(4)	$2.23\,\text{Hum} + 1.47\,\text{Rad} + 57.70 \pm 4.20$	.730
(5)	$0.90\,\text{Hum} + 1.78\,\text{Tib}_m + 71.29 \pm 3.49$	.823
(6)	$0.66\,\text{Fem}_m + 1.62\,\text{Tib}_m + 76.13 \pm 3.49$	.823
(7)	$1.15(\text{Fem}_m + \text{Tib}_m) + 71.04 \pm 3.53$	.818
	Terry Collection — Negro males (cadaver stature)[2]	
(1)	$0.95\,\text{Hum} + 0.35\,\text{Rad} + 0.60\,\text{Fem}_m + 1.20\,\text{Tib}_m + 57.68 \pm 3.54$	.891
(2)	$1.05\,\text{Hum} + 0.60\,\text{Fem}_m + 1.32\,\text{Tib}_m + 54.67 \pm 3.54$	.891
(3)	$1.36\,\text{Hum} + 1.10\,\text{Rad} + 0.93\,\text{Fem}_m + 54.90 \pm 3.74$	.878
(4)	$2.25\,\text{Hum} + 1.56\,\text{Rad} + 56.84 \pm 4.02$	.857
(5)	$1.42\,\text{Hum} + 1.68\,\text{Tib}_m + 60.89 \pm 3.66$	.883
(6)	$0.84\,\text{Fem}_m + 1.76\,\text{Tib}_m + 65.91 \pm 3.67$	.882
(7)	$1.26(\text{Fem}_m + \text{Tib}_m) + 65.36 \pm 3.77$	.876
	Terry Collection — White females (cadaver stature)[2]	
(1)	$0.68\,\text{Hum} - 0.04\,\text{Rad} + 1.18\,\text{Fem}_m + 1.16\,\text{Tib}_m + 52.74 \pm 3.51$	.884
(2)	$0.68\,\text{Hum} + 1.17\,\text{Fem}_m + 1.15\,\text{Tib}_m + 52.62 \pm 3.51$	.884
(3)	$0.80\,\text{Hum} + 0.65\,\text{Rad} + 1.71\,\text{Fem}_m + 50.47 \pm 3.66$	.873
(4)	$1.99\,\text{Hum} + 2.31\,\text{Rad} + 50.85 \pm 4.04$	.843
(5)	$1.35\,\text{Hum} + 1.95\,\text{Tib}_m + 55.27 \pm 3.67$	.872
(6)	$1.48\,\text{Fem}_m + 1.28\,\text{Tib}_m + 55.57 \pm 3.55$	.881
(7)	$1.39(\text{Fem}_m + \text{Tib}_m) + 55.70 \pm 3.55$	.881
	Terry Collection — Negro females (cadaver stature)[2]	
(1)	$0.44\,\text{Hum} - 0.20\,\text{Rad} + 1.46\,\text{Fem}_m + 0.86\,\text{Tib}_m + 58.83 \pm 3.22$	.870
(2)	$0.39\,\text{Hum} + 1.43\,\text{Fem}_m + 0.82\,\text{Tib}_m + 58.37 \pm 3.22$	.870
(3)	$0.80\,\text{Hum} - 0.01\,\text{Rad} + 1.85\,\text{Fem}_m + 56.68 \pm 3.29$	.864
(4)	$2.57\,\text{Hum} + 0.76\,\text{Rad} + 64.92 \pm 4.08$	.781
(5)	$1.08\,\text{Hum} + 1.79\,\text{Tib}_m + 65.30 \pm 3.58$	.836
(6)	$1.53\,\text{Fem}_m + 0.96\,\text{Tib}_m + 61.04 \pm 3.23$	.869
(7)	$1.26(\text{Fem}_m + \text{Tib}_m) + 62.22 \pm 3.28$	.865

[1] For estimation of the stature of individuals above 30 years of age subtract .06 (age − 30) cm from the derived estimates.

[2] Corrected for age to estimate maximum cadaver stature.

other bones are available, since the bones of the upper limb result in greater errors of estimate than the bones of the lower limb.

Estimation of long bone lengths from femur$_m$. The intercorrelations among the various bone lengths provide the necessary statistics for constructing estimation equations for any bone length in terms of the length of another bone. Such equations make possible the comparison of various populations

TABLE 12

Equations for estimation of length of long bones (cm) from the length of the femur$_m$ (with standard errors) according to source, race and sex

Military personnel	
WHITE MALE	NEGRO MALE
Hum = .61 Fem$_m$ + 4.79 ± 0.88	Hum = .45 Fem$_m$ + 12.04 ± 0.86
Rad = .42 Fem$_m$ + 5.30 ± 0.82	Rad = .38 Fem$_m$ + 8.20 ± 0.89
Ulna = .42 Fem$_m$ + 7.18 ± 0.83	Ulna = .40 Fem$_m$ + 9.17 ± 0.97
Tib$_m$ = .81 Fem$_m$ — 0.45 ± 1.06	Tib$_m$ = .86 Fem$_m$ — 2.02 ± 1.21
Fib = .78 Fem$_m$ + 1.27 ± 1.01	Fib = .85 Fem$_m$ — 1.32 ± 1.28
Terry Collection	
WHITE FEMALE	NEGRO FEMALE
Hum = .60 Fem$_m$ + 4.65 ± 0.84	Hum = .54 Fem$_m$ + 7.16 ± 0.91
Rad = .43 Fem$_m$ + 3.74 ± 0.60	Rad = .44 Fem$_m$ + 4.37 ± 1.03
Ulna = .45 Fem$_m$ + 4.66 ± 0.75	Ulna = .39 Fem$_m$ + 8.34 ± 0.91
Tib$_m$ = .77 Fem$_m$ + 0.95 ± 0.91	Tib$_m$ = .78 Fem$_m$ + 1.32 ± 1.05
Fib = .77 Fem$_m$ + 1.26 ± 0.89	Fib = .77 Fem$_m$ + 1.89 ± 1.00

insofar as the relationship among their bone lengths is concerned. Pearson has compared Naqada, Aino and French samples by such formulae. Comparisons have been made also (Dupertuis and Hadden) by using ratios of mean bone lengths, such as, tibia/femur or radius/humerus. These ratios imply a linear relationship of the form, $y = ax$. However, the general best fitting linear equation is of the form, $y = ax + b$. Unless b is negligible the ratio varies for different values of x. Thus, for samples which differ in the average length of the reference bone (x) it is possible to obtain a different ratio even though the same estimation equation of y from x would pertain to both samples.

The length of $femur_m$ has been chosen arbitrarily as the reference bone length from which estimation equations of other bone lengths for each of the samples are obtained. The resultant equations and the corresponding standard errors of estimate are presented in table 12 for the military White and Negro male samples and for the White and Negro female samples from the Terry Collection. By inserting the average length of $femur_m$ for a different sample into these formulae and comparing the resultant estimate with the actual average length, it is possible to determine whether or not this difference is larger than might be expected in random sampling from the same population, provided the method of measuring is the same.

The equations for estimation of lengths (cm) of various bones based on the military personnel (table 12) were applied to the males of the Terry Collection with the following results:

	WHITE MALE		NEGRO MALE	
	Length (cm)		Length (cm)	
	Estimated	Observed	Estimated	Observed
Humerus	32.64	33.00	33.38	33.78
Radius	24.48	24.40	26.22	26.32
Ulna	26.36	26.22	28.14	28.16
$Tibia_m$	36.53	36.37	38.76	38.72
Fibula	36.88	36.78	38.99	38.95

The estimated bone lengths are in very close agreement with the observed average bone lengths for these samples of the Terry Collection except for the humerus. Thus it appears that the male samples of the Terry Collection differ from the military personnel in having humeri that are relatively longer, but that the other bones from these two sources are quite comparable.

Comparison of equations for estimation of stature derived from military personnel with those derived from the Terry

Collection subjects. Data from the subjects of the military personnel and the Terry Collection have been treated so far in this study by parallel methods. This has made possible a comparison between the equations resulting from the two sources, and, an appraisal of the applicability of the equations derived from the military personnel to American White and Negro males of different age and socio-economic status. It is likewise believed that the comparison provides evidence for an evaluation of the equations for the females of both races, which of necessity have been determined only from data of the Terry Collection.

In order to compare directly the estimates of stature obtained from the military personnel and from the subjects of the Terry Collection it is necessary to take into account the difference between statures measured on the living and on the cadaver. As has been indicated, the equations have already been extended to cover the effect of ageing on stature by the addition of a linear factor relating stature to age.

The amount of adjustment required to convert cadaver to living stature is not considered to be the same by all investigators. Manouvrier concluded that stature measured on the cadaver was on the average 2 cm greater than if measured on the living subject. This amount of increase was utilized by Telkkä. Pearson estimated the increase to be 1.2 cm for males and 2 cm for females. On the other hand, Dupertuis and Hadden accepted the cadaver statures, which had been measured by Todd, to be in substantial agreement with the living statures. It is very likely that no one value can be applied in general but that the amount of needed correction differs according to the method used in measuring cadaver stature. In those cases where an attempt was made to determine the necessary correction it has been done on the basis of the difference between the average cadaver stature of the sample and some independent estimate of the mean stature of the total population. However, such an approach fails to take into account the fact that the mean stature of a population may have been affected by a recent secular trend indicating that a fair comparison requires means obtained from groups living in the same period. Also, this method ignores the fact that the sample of cadavers may not have been a random sample from the total population.

The average difference between cadaver and living statures for the present samples has been determined on the basis of the equations for estimation of stature for the White males from the two sources. This method is feasible since secular trends in stature have been shown to be accompanied by corresponding trends in length of long bones (Trotter and Gleser). Estimation of stature by the complete multiple regression equation for military White males should give the average living stature of White males from the Terry Collection to within an accuracy of 0.5 cm whereas the comparable equation based on the Terry Collection sample should estimate cadaver stature for the military personnel to within the same error. The average of the differences between these estimates and the recorded values, then, would approximate the difference between living and cadaver statures. The estimated cadaver stature for the White males of the military personnel is 176.725 cm (utilizing the multiple regression equation (2) in table 11,[3] based on White males of the Terry Collection) and their living stature is 174.035 cm (see table 8); the difference between the two is 2.69 cm. The living stature of the White males of the Terry Collection (utilizing the corresponding equation based on the military personnel) is 169.94 cm and the cadaver stature adjusted for age is 172.29 cm; the difference is 2.35 cm. The average correction is, therefore, 2.5 cm to one decimal place. Since it is reasonable to assume that the difference between living and cadaver stature is constant for a particular method of measurement, this same amount of correction was applied to the statures of the Negro males and to the female groups. The estimated statures for the 4 groups from the

[3] Equation (2) was used since the weight for radius in equation (1) is essentially zero for both groups.

Terry Collection converted to living statures (cm), therefore, are as follows:

	AT AGE OF DEATH	MAXIMUM (18–30 YEARS)
White males	167.89	169.79
Negro males	170.23	171.40
White females	158.18	160.22
Negro females	158.39	159.42

In figures 2 and 3 the equations obtained from the data of White and Negro military personnel are compared to the corresponding equations from data of the Terry Collection subjects, corrected for age and living stature. For White

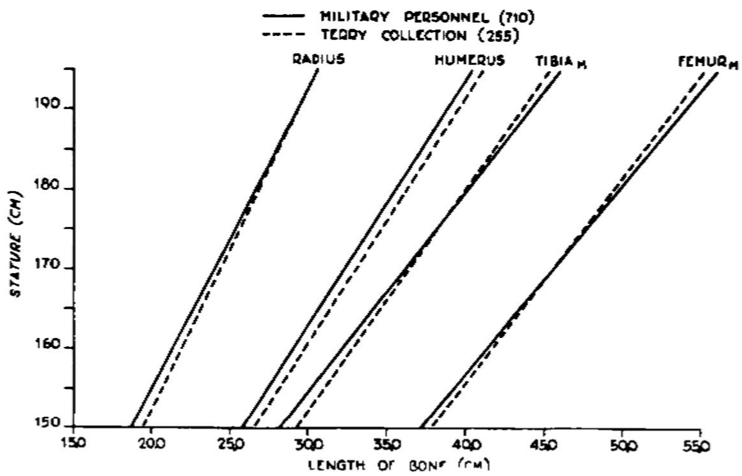

Fig. 2 Comparison of estimates of stature according to length of long bones of White males of military personnel and Terry Collection. (Data from Terry Collection subjects have been converted to maximum living stature.)

males, substantial agreement is apparent in the stature estimates which would be obtained for any particular length of long bone throughout the range. The difference in estimate is less than 1.5 cm for all but those based on the shortest of the tibiae and radii. The equations based on the humerus give a constant difference in estimated stature, but this is not surprising since it has already been noted that the average length of the humerus of White males is relatively longer for the Terry Collection than for the military personnel. It is certain that the equations based on military personnel which have been recommended for use (Tib_m, Fem_m, or the combination of the two), would estimate adequately the stature of the White males of the Terry Collection. The agreement is quite satisfactory, also, for the estimation equations for the Negroes ex-

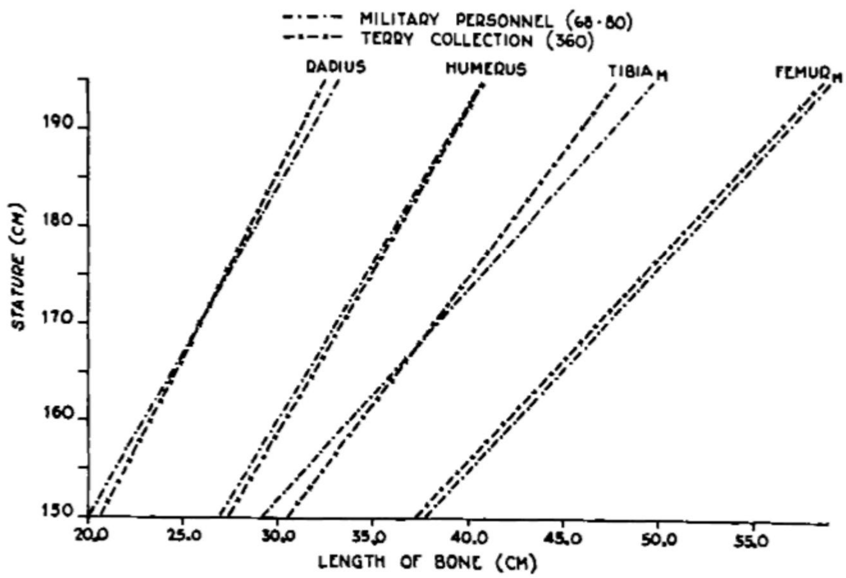

Fig. 3 Comparison of estimates of stature according to length of long bones of Negro males of military personnel and Terry Collection. (Data from Terry Collection subjects have been converted to maximum living stature.)

cepting in the case of the tibia. For this bone there is some divergence in the slopes of the equations which results in a difference in stature estimate at the extremes of the slopes of approximately 3 cm. Since all the equations are so nearly alike, however, despite the limited number of cases on which the military Negro stature equations were computed, it is evident that the latter are quite adequate for estimating living stature of Negro males.

The final equations for estimation of living stature of Whites and Negroes of both sexes, extended to cover all ages, are presented in table 13. The equations applicable to males are from the military personnel while those for females are the corrected equations from the Terry Collection samples. Appendixes to the table present stature estimations according to a wide range of lengths of long bones for each sex of each race.

TABLE 13

Equations for estimation of living stature (cm) (with standard errors) from long bones for American Whites and Negroes between 18 and 30 years of age[1]

WHITE MALES		NEGRO MALES	
3.08 Hum + 70.45	± 4.05	3.26 Hum + 62.10	± 4.43
3.78 Rad + 79.01	± 4.32	3.42 Rad + 81.56	± 4.30
3.70 Ulna + 74.05	± 4.32	3.26 Ulna + 79.29	± 4.42
2.38 Fem_m + 61.41	± 3.27	2.11 Fem_m + 70.35	± 3.94
2.52 Tib_m + 78.62	± 3.37	2.19 Tib_m + 86.02	± 3.78
2.68 Fib + 71.78	± 3.29	2.19 Fib + 85.65	± 4.08
1.30(Fem_m + Tib_m) + 63.29	± 2.99	1.15(Fem_m + Tib_m) + 71.04	± 3.53
1.42 Fem_m + 1.24 Tib_m + 59.88	± 2.99	0.66 Fem_m + 1.62 Tib_m + 76.13	± 3.49
0.93 Hum + 1.94 Tib_m + 69.30	± 3.26	0.90 Hum + 1.78 Tib_m + 71.29	± 3.49
0.27 Hum + 1.32 Fem_m + 1.16 Tib_m + 58.57[2]	± 2.99	0.89 Hum — 1.01 Rad + 0.38 Fem_m + 1.92 Tib_m + 74.56	± 3.38
WHITE FEMALES		**NEGRO FEMALES**	
3.36 Hum + 57.97	± 4.45	3.08 Hum + 64.67	± 4.25
4.74 Rad + 54.93	± 4.24	2.75 Rad + 94.51	± 5.05
4.27 Ulna + 57.76	± 4.30	3.31 Ulna + 75.38	± 4.83
2.47 Fem_m + 54.10	± 3.72	2.28 Fem_m + 59.76	± 3.41
2.90 Tib_m + 61.53	± 3.66	2.45 Tib_m + 72.65	± 3.70
2.93 Fib + 59.61	± 3.57	2.49 Fib + 70.90	± 3.80
1.39(Fem_m + Tib_m) + 53.20	± 3.55	1.26(Fem_m + Tib_m) + 59.72	± 3.28
1.48 Fem_m + 1.28 Tib_m + 53.07	± 3.55	1.53 Fem_m + 0.96 Tib_m + 58.54	± 3.23
1.35 Hum + 1.95 Tib_m + 52.77	± 3.67	1.08 Hum + 1.79 Tib_m + 62.80	± 3.58
0.68 Hum + 1.17 Fem_m + 1.15 Tib_m + 50.12[2]	± 3.51	0.44 Hum — 0.20 Rad + 1.46 Fem_m + 0.86 Tib_m + 56.33	± 3.22

[1] To estimate stature of older individuals subtract .06 (age in years − 30) cm; to estimate cadaver stature add 2.5 cm.

[2] This equation is presented in preference to that involving the radius since the weight of the radius is essentially zero.

TABLE 13

APPENDIX 1

*Expected maximum stature * from long bone lengths (maximum) for American White males*

HUM	RAD	ULNA	STATURE		FEM	TIB	FIB	FEM + TIB
mm	*mm*	*mm*	*cm*	*in* **	*mm*	*mm*	*mm*	*mm*
265	193	211	152	59^{7}	381	291	299	685
268	196	213	153	60^{2}	385	295	303	693
271	198	216	154	60^{5}	389	299	307	701
275	201	219	155	61	393	303	311	708
278	204	222	156	61^{3}	398	307	314	716
281	206	224	157	61^{6}	402	311	318	723
284	209	227	158	62^{2}	406	315	322	731
288	212	230	159	62^{5}	410	319	326	738
291	214	232	160	63	414	323	329	746
294	217	235	161	63^{3}	419	327	333	753
297	220	238	162	63^{6}	423	331	337	761
301	222	240	163	64^{1}	427	335	340	769
304	225	243	164	64^{5}	431	339	344	776
307	228	246	165	65	435	343	348	784
310	230	249	166	65^{3}	440	347	352	791
314	233	251	167	65^{6}	444	351	355	799
317	235	254	168	66^{1}	448	355	359	806
320	238	257	169	66^{4}	452	359	363	814
323	241	259	170	66^{7}	456	363	367	821
327	243	262	171	67^{3}	461	367	370	829
330	246	265	172	67^{6}	465	371	374	837
333	249	267	173	68^{1}	469	375	378	844
336	251	270	174	68^{4}	473	379	381	852
339	254	273	175	68^{7}	477	383	385	859
343	257	276	176	69^{2}	482	386	389	867
346	259	278	177	69^{5}	486	390	393	874
349	262	281	178	70^{1}	490	394	396	882
352	265	284	179	70^{4}	494	398	400	889
356	267	286	180	70^{7}	498	402	404	897
359	270	289	181	71^{2}	503	406	408	905
362	272	292	182	71^{5}	507	410	411	912
365	275	294	183	72	511	414	415	920
369	278	297	184	72^{4}	515	418	419	927
372	280	300	185	72^{7}	519	422	422	935
375	283	303	186	73^{2}	524	426	426	942
378	286	305	187	73^{5}	528	430	430	950
382	288	308	188	74	532	434	434	957
385	291	311	189	74^{3}	536	438	437	965
388	294	313	190	74^{6}	540	442	441	973
391	296	316	191	75^{2}	545	446	445	980
395	299	319	192	75^{5}	549	450	449	988
398	302	321	193	76	553	454	452	995
401	304	324	194	76^{3}	557	458	456	1003
404	307	327	195	76^{6}	561	462	460	1010
408	309	330	196	77^{1}	566	466	463	1018
411	312	332	197	77^{4}	570	470	467	1026
414	315	335	198	78	574	474	471	1033

* The expected maximum stature should be reduced by the amount of .06 (age in years − 30) cm to obtain expected stature of individuals over 30 years of age.

** The raised number indicates the numerator of a fraction of an inch expressed in eighths, thus 59^{7} should be read 59⅞ inches.

TABLE 13

APPENDIX 2

*Expected maximum stature * from long bone lengths (maximum) for American Negro males*

HUM	RAD	ULNA	STATURE		FEM	TIB	FIB	FEM + TIB
mm	*mm*	*mm*	*cm*	*in ***	*mm*	*mm*	*mm*	*mm*
276	206	223	152	59^{7}	387	301	303	704
279	209	226	153	60^{2}	391	306	308	713
282	212	229	154	60^{5}	396	310	312	721
285	215	232	155	61	401	315	317	730
288	218	235	156	61^{3}	406	320	321	739
291	221	238	157	61^{6}	410	324	326	747
294	224	242	158	62^{2}	415	329	330	756
297	226	245	159	62^{5}	420	333	335	765
300	229	248	160	63	425	338	339	774
303	232	251	161	63^{3}	430	342	344	782
306	235	254	162	63^{6}	434	347	349	791
310	238	257	163	64^{1}	439	352	353	800
313	241	260	164	64^{5}	444	356	358	808
316	244	263	165	65	449	361	362	817
319	247	266	166	65^{3}	453	365	367	826
322	250	269	167	65^{6}	458	370	371	834
325	253	272	168	66^{1}	463	374	376	843
328	256	275	169	66^{4}	468	379	381	852
331	259	278	170	66^{7}	472	383	385	861
334	262	281	171	67^{3}	477	388	390	869
337	264	284	172	67^{6}	482	393	394	878
340	267	287	173	68^{1}	487	397	399	887
343	270	291	174	68^{4}	491	402	403	895
346	273	294	175	68^{7}	496	406	408	904
349	276	297	176	69^{2}	501	411	413	913
352	279	300	177	69^{5}	506	415	417	921
356	282	303	178	70	510	420	422	930
359	285	306	179	70^{4}	515	425	426	939
362	288	309	180	70^{7}	520	429	431	947
365	291	312	181	71^{2}	525	434	435	956
368	294	315	182	71^{5}	529	438	440	965
371	297	318	183	72	534	443	445	974
374	300	321	184	72^{4}	539	447	449	982
377	302	324	185	72^{7}	544	452	454	991
380	305	327	186	73^{2}	548	456	458	1000
383	308	330	187	73^{5}	553	461	463	1008
386	311	333	188	74	558	466	467	1017
389	314	336	189	74^{3}	563	470	472	1026
392	317	340	190	74^{6}	567	475	476	1034
395	320	343	191	75^{2}	572	479	481	1043
398	323	346	192	75^{5}	577	484	486	1052
401	326	349	193	76	582	488	490	1061
405	329	352	194	76^{3}	586	493	495	1069
408	332	355	195	76^{6}	591	498	499	1078
411	335	358	196	77^{1}	596	502	504	1087
414	337	361	197	77^{4}	601	507	508	1095
417	340	364	198	78	605	511	513	1104

* The expected maximum stature should be reduced by the amount of .06 (age in years − 30) cm to obtain expected stature of individuals over 30 years of age.

** The raised number indicates the numerator of a fraction of an inch expressed in eighths, thus 59^{7} should be read $59\frac{7}{8}$ inches.

TABLE 13

APPENDIX 3

*Expected maximum stature * from long bone lengths (maximum) for American White females*

HUM	RAD	ULNA	STATURE		FEM	TIB	FIB	FEM + TIB
mm	*mm*	*mm*	*cm*	*in* **	*mm*	*mm*	*mm*	*mm*
244	179	193	140	55^{1}	348	271	274	624
247	182	195	141	55^{4}	352	274	278	632
250	184	197	142	55^{7}	356	277	281	639
253	186	200	143	56^{2}	360	281	285	646
256	188	202	144	56^{6}	364	284	288	653
259	190	204	145	57^{1}	368	288	291	660
262	192	207	146	57^{4}	372	291	295	668
265	194	209	147	57^{7}	376	295	298	675
268	196	211	148	58^{2}	380	298	302	682
271	198	214	149	58^{5}	384	302	305	689
274	201	216	150	59	388	305	309	696
277	203	218	151	59^{4}	392	309	312	704
280	205	221	152	59^{7}	396	312	315	711
283	207	223	153	60^{2}	400	315	319	718
286	209	225	154	60^{5}	404	319	322	725
289	211	228	155	61	409	322	326	732
292	213	230	156	61^{3}	413	326	329	740
295	215	232	157	61^{6}	417	329	332	747
298	217	235	158	62^{2}	421	333	336	754
301	220	237	159	62^{5}	425	336	340	761
304	222	239	160	63	429	340	343	768
307	224	242	161	63^{3}	433	343	346	776
310	226	244	162	63^{6}	437	346	349	783
313	228	246	163	64^{1}	441	350	353	790
316	230	249	164	64^{5}	445	353	356	797
319	232	251	165	65	449	357	360	804
322	234	253	166	65^{3}	453	360	363	812
324	236	256	167	65^{6}	457	364	366	819
327	239	258	168	66^{1}	461	367	370	826
330	241	261	169	66^{4}	465	371	373	833
333	243	263	170	66^{7}	469	374	377	840
336	245	265	171	67^{2}	473	377	380	847
339	247	268	172	67^{6}	477	381	384	855
342	249	270	173	68^{1}	481	384	387	862
345	251	272	174	68^{4}	485	388	390	869
348	253	275	175	68^{7}	489	391	394	876
351	255	277	176	69^{2}	494	395	397	883
354	258	279	177	69^{5}	498	398	401	891
357	260	282	178	70^{1}	502	402	404	898
360	262	284	179	70^{4}	506	405	407	905
363	264	286	180	70^{7}	510	409	411	912
366	266	289	181	71^{2}	514	412	414	919
369	268	291	182	71^{5}	518	415	418	927
372	270	293	183	72	522	419	421	934
375	272	296	184	72^{4}	526	422	425	941

* The expected maximum stature should be reduced by the amount of .06 (age in years − 30) cm to obtain expected stature of individuals over 30 years of age.

** The raised number indicates the numerator of a fraction of an inch expressed in eighths, thus 55^{1} should be read $55\frac{1}{8}$ inches.

TABLE 13

APPENDIX 4

*Expected maximum stature * from long bone lengths (maximum) for American Negro females*

HUM	RAD	ULNA	STATURE		FEM	TIB	FIB	FEM + TIB
mm	*mm*	*mm*	*cm*	*in* **	*mm*	*mm*	*mm*	*mm*
245	165	195	140	55^{1}	352	275	278	637
248	169	198	141	55^{4}	356	279	282	645
251	173	201	142	55^{7}	361	283	286	653
254	176	204	143	56^{2}	365	287	290	661
258	180	207	144	56^{6}	369	291	294	669
261	184	210	145	57^{1}	374	295	298	677
264	187	213	146	57^{4}	378	299	302	685
267	191	216	147	57^{7}	383	303	306	693
271	195	219	148	58^{2}	387	308	310	701
274	198	222	149	58^{5}	391	312	314	709
277	202	225	150	59	396	316	318	717
280	205	228	151	59^{4}	400	320	322	724
284	209	231	152	59^{7}	405	324	326	732
287	213	235	153	60^{2}	409	328	330	740
290	216	238	154	60^{5}	413	332	334	748
293	220	241	155	61	418	336	338	756
297	224	244	156	61^{3}	422	340	342	764
300	227	247	157	61^{6}	426	344	346	772
303	231	250	158	62^{2}	431	348	350	780
306	235	253	159	62^{5}	435	352	354	788
310	238	256	160	63	440	357	358	796
313	242	259	161	63^{3}	444	361	362	804
316	245	262	162	63^{6}	448	365	366	812
319	249	265	163	64^{1}	453	369	370	820
322	253	268	164	64^{5}	457	373	374	828
326	256	271	165	65	462	377	378	836
329	260	274	166	65^{3}	466	381	382	843
332	264	277	167	65^{6}	470	385	386	851
335	267	280	168	66^{1}	475	389	390	859
339	271	283	169	66^{4}	479	393	394	867
342	275	286	170	66^{7}	484	397	398	875
345	278	289	171	67^{3}	488	401	402	883
348	282	292	172	67^{6}	492	406	406	891
352	285	295	173	68^{1}	497	410	410	899
355	289	298	174	68^{4}	501	414	414	907
358	293	301	175	68^{7}	505	418	418	915
361	296	304	176	69^{2}	510	422	422	923
365	300	307	177	69^{5}	514	426	426	931
368	304	310	178	70^{1}	519	430	430	939
371	307	313	179	70^{4}	523	434	434	947
374	311	316	180	70^{7}	527	438	438	955
378	315	319	181	71^{2}	532	442	442	963
381	318	322	182	71^{5}	536	446	446	970
384	322	325	183	72	541	450	450	978
387	325	328	184	72^{4}	545	454	454	986

* The expected maximum stature should be reduced by the amount of .06 (age in years − 30) cm to obtain expected stature of individuals over 30 years of age.

** The raised number indicates the numerator of a fraction of an inch expressed in eighths, thus 55^{1} should be read $55\frac{1}{8}$ inches.

Test of stature estimation equations by application to a new sample. Equations obtained by curve fitting and regression techniques reflect any bias inherent in the constitution of the sample. The application of such equations to a new sample may result in an error larger than predicted by the sampling statistics. This result is not likely to occur if the original sample represented a truly random selection from the population to which the equations are subsequently applied, but the population may have been ill-defined and the sample one of convenience. For example, Pearson found that his equations (based on the French data) resulted in a poor estimation of stature for 7 French criminals. He attributed this to the bias of the second sample, but it may have been rather the bias of the original sample from the standpoint of age, socio-economic status and restricted range of statures.

In the present study among the military personnel were 368 White males with miscellaneous absences of long limb bones. These provided an opportunity for an independent check of the pertinent formulae. In this group were 100 cases for which data of the paired arm, thigh and leg bones were present. These cases have been utilized as the validation sample. Stature was estimated to the nearest centimeter according to formulae involving each of the three bones and also the formula involving length of $femur_m$ plus $tibia_m$. These estimates were compared with the statures recorded at the time of induction into military service. The range of errors and the mean error are presented in table 14 together with the percentage of statures estimated to within 3 cm of the true stature, the obtained standard error of estimate (standard deviation of estimates from true stature) and the standard error of estimate as predicted from the correlations in the original samples.

It may be seen that each of the 4 equations has resulted in an almost exact estimation of the average stature of the new sample, since the mean errors are practically zero. The obtained standard error of estimate for each equation also compares favorably to the expected standard error of estimate. For a normal distribution, the standard error of estimate provides the range of errors of approximately two-thirds of the cases. In this new sample more than two-thirds of the cases lie within such a range. In point of fact, using any of the equations except that based on the humerus, two-thirds or more of the resultant estimates deviate from the true stature by 3 cm or less. Evidently the obtained standard error of estimate is increased by a few extreme cases. For approximately 79% of American military White males the statures can be estimated to within an accuracy of 3 cm (1.2 inches) by the equation utilizing $femur_m$ plus $tibia_m$. Thus, equations based on White males of military personnel have been applied to a new sample

TABLE 14

Statistics (cm) obtained from application of selected equations for estimation of stature to a new sample of 100 military White males

EQUATION FROM TABLE 13 BASED ON	MEAN ERROR FOR GROUP	RANGE OF ERRORS OF ESTIMATE	% WITHIN 3 CM OF TRUE STATURE	OBTAINED S.E. OF ESTIMATE	EXPECTED S.E. OF ESTIMATE
Humerus	—.12	—9 to +9	62	3.66	4.05
$Femur_m$	—.02	—6 to +9	69	3.22	3.27
$Tibia_m$	00	—7 to +10	70	3.35	3.37
(Fem_m + Tib_m)	+.08	—6 to +9	79	3.05	2.99

drawn from the same population and have been shown to provide estimates of stature well within the expected range of accuracy. It has already been shown that these formulae are adequate for a sample such as that provided by the Terry Collection when the difference in age and method of measuring stature are taken into account. It can be concluded that these equations may be applied without reservation to the entire population of American White males. It would be worth while to test the formulae for Negro males and for White and Negro females, were independent samples available from the same populations. By extrapolation of evidence for the White males of military personnel it is suggested that formulae for the other three groups will provide uniformly accurate estimates when applied to the pertinent race and sex.

Comparison of equations for estimation of stature. In addition to the formulae derived from the present samples for estimation of stature from long bones there are available also the equations and/or tables of Rollet, Manouvrier, and Pearson based on data of French males and females; of Breitinger on German males; of Telkkä on Finnish males and females; and of Dupertuis and Hadden on American Whites and Negroes of both sexes. Thus, several different populations have been studied with more or less representative samples. The question now arises as to what generalizations can be drawn regarding the suitability of any particular set of equations for a specific problem of stature estimation.

There are several aspects to consider in making comparisons among the various formulae. In the first place, it is unquestionably true that the equations for estimation of stature derived from a particular sample will provide the most accurate estimate of stature for that sample. This does not necessarily mean that they will be the best suited for the general population from which the sample was drawn since the sample may have been a biased one (i.e. not a random selection). The suitability is particularly open to question if assumptions had been necessary in the determination of the additive constant. For example, in adapting Rollet's data to living stature estimation, Pearson had to deduce the average length of dry bones from the length of humid bones; the average length of bones without cartilage from bones with cartilage; and the average stature of the living population from cadaver stature. In addition, his sample was composed almost entirely of middle-aged or old individuals averaging about 60 years. On the basis of his equations stature for a young adult population such as, for example, French military males would be estimated almost 2 cm too short due to this ageing factor alone. If an adjustment for age is made it is still doubtful that the estimates would be accurate for tall individuals because of the limited range of statures in the original sample. Evidence that Pearson's equations may not necessarily be the best for Frenchmen in general lies in his own experience of estimating the stature of 7 French criminals. The average estimate was 2.73 cm below the actual statures, whereas the equation based on the femur of the present White male sample yields an average error of only — .53 cm for the group.

Telkkä's equations suffer from similar limitations, namely, the smallness of the sample, the possible sampling bias in cadaver material, the transformation of cadaver measurements to living stature and the uncontrolled age factor. Breitinger avoided two of these difficulties by measuring a large sample of young adult living subjects but introduced the liability involved in converting measurements between palpable bony prominences on the living to measurements of dry bones. Dupertuis and Hadden utilized reasonably large samples each with an adequate range of stature excepting the White males. But their samples were drawn from the lower socio-economic level, no allowance was made for change in stature from ageing, and it was assumed that Todd's measurements of cadaver stature represent living stature. This latter assumption may be open to question in the light of experience with measurements of cadaver stature for the Terry Collection.

In applying formulae derived from data of a particular group to bone measurements from another population the possibility of differences in the relationship between bone length and stature for the two populations must be recognized. However, many workers have attributed discrepancies between estimated and observed statures to differences in the constitution of the populations involved, although much of the discrepancy may be due to differences in sampling, in methods of measurement of stature and bone lengths, and in the consequent necessary adjustments of constants. How much the differences between the various equations for estimation of stature reflect actual differences in the relationship of stature to long bone length in the national groups on which they were formulated and how much they reflect the above mentioned differences is difficult to evaluate.

It is perhaps impossible to determine which equations are best for application to skeletal remains of older races for which there are no records of actual stature. In fact, Kurth ('50) has suggested on the basis of his recent experience in estimating stature of middle Europeans of the 8th to 10th century that measurement, when possible, of the overall length of the skeletal remains *in situ* is preferable to stature estimated from the long bones according to equations based on more recent populations. On the other hand, when the question is one of determining the best equations for stature estimation in a particular population of the present era, such as the American White male, it is possible to obtain a direct answer by testing available equations on a new sample of known living stature. As already noted, such a sample of 100 American military White males is available with data of the paired arm, thigh and leg bones. The mean actual stature of this group was 173.41 cm with a standard deviation of 6.11 cm. Estimates based on the length of the humerus and femur_m only were compared since slight differences exist in the methods of measuring the tibia.

In table 15 is listed the investigator, his equation and the standard error of estimate for the sample from which the equation was derived. The obtained standard error of estimate, indicated in the table, is the standard deviation of the actual statures for this sample about the line of regression. Obviously, if there is an error in the estimation of the mean stature of the new sample there will be a corresponding increment in the standard error of estimate even though the slope of the regression equation is adequate to represent the regression in the new sample. Conversely, if the slope of the equation differs considerably from the line of regression of the sample, but the means correspond, the estimate may be accurate at and near the mean, but become increasingly inaccurate for progressively shorter or taller statures. In table 15 are listed also the mean and standard deviation of errors of estimate and the range of errors for each equation in order to indicate not only the amount, but also the type, of error which is incurred in the estimation of stature for this sample. Negative deviations indicate that the estimate is smaller than the actual stature and positive values indicate the reverse. The larger the standard deviation the poorer is the fit of the slope of regression whereas the mean deviation is an indication of the constant error. Approximately two-thirds of the errors in each case lie within the range of the mean error ± the standard deviation.

TABLE 15

Errors of estimation of stature (cm) of 100 additional military White males and the obtained standard error of estimated statures according to equations (with standard errors) of certain investigators based on lengths of femur$_m$ and humerus

INVESTIGATOR	EQUATION	OBTAINED S.E. OF ESTIMATE	ERRORS OF ESTIMATION		
			Range	Mean	S.D.
		Femur$_m$			
Breitinger ('37)	1.64 Fem + 94.31 ± 4.8	3.93	− 10 to + 6	− 1.66	3.57
Dupertuis and Hadden ('51)	2.12 Fem + 77.05 ± 3.4	4.68	− 3 to + 11	+ 3.22	3.40
Manouvrier (1892)	Table	5.63	− 12 to + 5	− 4.38	3.53
Pearson (1899)	1.88 Fem + 81.31 ± 3.2	5.02	− 11 to + 4	− 3.67	3.43
Telkkä ('50)	2.10 Fem + 71.85 ± 4.9	4.28	− 9 to + 5	− 2.74	3.28
Present study	2.38 Fem + 61.41 ± 3.3	3.22	− 6 to + 9	− 0.02	3.22
		Humerus			
Breitinger ('37)	2.72 Hum + 83.21 ± 4.9	4.03	− 10 to + 8	− 1.63	3.69
Dupertuis and Hadden ('51)	2.27 Hum + 98.34 ± 4.6	4.00	− 8 to + 10	+ 0.80	3.92
Manouvrier (1892)	Table	7.07	− 15 to + 7	− 5.76	4.10
Pearson (1899)	2.89 Hum + 70.64 ± 3.2	7.15	− 15 to + 3	− 6.22	3.53
Telkkä ('50)	2.80 Hum + 75.28 ± 5.0	5.80	− 12 to + 5	− 4.57	3.58
Present study	3.08 Hum + 70.45 ± 4.0	3.66	− 9 to + 9	− 0.12	3.65

From table 15 it is evident that the equations (based on femur and humerus) developed in this study provide a more accurate estimate of stature for American White males of military age than do the other equations that have been tested. The estimated mean stature of the group is accurate and the obtained standard error of estimation is the smallest. Manouvrier's, Pearson's and Telkkä's equations result in stature estimates which are much too low for American military males while those of Dupertuis and Hadden are too high.

A comparison of estimates between femur and humerus indicates that the range of errors in every case is smaller for the femur. Its mean error is likewise substantially smaller for all estimates except for those of Breitinger and Dupertuis and Hadden. Equations of the former give practically equivalent results for the two bones whereas those of the latter give more accurate estimates with the humerus than with the femur. The superiority of the equation for the humerus in the case of Dupertuis and Hadden is due to two compensating factors. Their subjects like those of Rollet, Telkkä, and the Terry Collection have upper limbs which are relatively longer than lower limbs when compared to the military subjects. For all such groups the estimate derived from the humerus is lower than that derived from the associated femur when applied to the military subjects. However, the estimate of mean stature from the equation of Dupertuis and Hadden based on the femur is considerably greater than the true mean, probably the result of their use of cadaver stature as equivalent to living stature. Thus, their lower estimate obtained from the humerus lies closer to the actual stature of the military group than does that obtained from the femur.

Another comparison of various equations of stature estimation was based only on the femur. The equation of each investigator has been applied (as directed by him to obtain living stature) to the mean femur length of every other sample of like sex. The application of equations obtained in the present study involved age corrections when pertinent. The mean deviation of the resulting stature estimate from the mean stature of each sample is given in table 16. It may be seen that for White males the present equations overestimate only slightly the statures of the French, Finnish, and German samples, and that these estimates deviate from the means less than do the estimates derived for the present sample according to the equations of Pearson, Telkkä and Breitinger. This difference is due mainly to the fact that the present equations provide for age differences among the groups. For the White females, the ages are more nearly comparable and thus the

equations of Telkkä and Pearson underestimate the mean of the present sample approximately to the same extent that the present equations overestimate the means of these samples. The equations of Dupertuis and Hadden overestimate considerably the means for every group. Their equations for Negroes even overestimate the mean statures of the White groups of the present study. It is well known that Negroes have shorter statures relative to length of femur than do Whites. Thus, it is evident that the cadaver statures as measured by Todd are greater than living statures, and that a correction is needed for these equations in this regard.

Comparison of the differences between long bone lengths and statures associated with race and sex. Many different statistics have been utilized in attempts to determine the type of variation in lengths of long bones and stature and in the relationship between these measurements associated with race and sex. The means and standard deviations of measurements obtained from various samples can be compared for significant differences. However, it is necessary that other factors, such as age, socio-economic status, period of birth, etc., be carefully controlled. The subjects constituting the Terry Collection are quite comparable with regard to these factors and a comparison for differences between these Whites and Negroes and males and females should be valid.

An examination of table 5 reveals that the Negro males and females have significantly longer bones on the average than have the corresponding sexes of the White race. (The only exception to this is the humerus of the female which does not differ significantly in length between the two races.) Also, the Negro males are significantly taller than the White males, whereas the females of the two races have an approximately equivalent stature. It may be noted in passing that in the military personnel group, the Negro male is significantly shorter on the average than the White male. Recent secular trends in stature may partially account for these apparently contradictory findings. Such findings further illustrate the necessity of defining carefully the populations from which samples are drawn for comparison. The Negro males show greater variability in every measurement than do the White males or the females of either race. The differences are statistically significant for most measurements. The White and Negro females do not differ significantly in variability nor do the White males and females.

A more interesting type of comparison between the races and sexes is that of the relative length of limb segments to each other and to stature. To this end, the ratios of average lengths in different groups have often been compared. However, such ratios can present misleading results when groups with different general size factors are compared. For example, Hrdlička ('47) indicates little or no sex difference for either the White or Negro race in the ratio of length of femur to stature, a result which was substantiated by Dupertuis and Hadden. However, when the equations for estimation of stature of Dupertuis and Hadden and of Pearson are applied it is seen that for a given length of femur the male is taller than the female.

It would appear that more meaningful questions to be answered are whether or not for a given length of one variable the groups to be compared differ in regard to other variables; and, throughout what range of measurements such differences hold true. Thus, it might be asked which sex or which race is taller when individuals with the same length of tibia or femur are compared. To answer this question the linear regression equation is admirably suited since it represents the rectified average measurement in the dependent variable for any given value of the independent variable, throughout the range of measurements. A great number of such comparisons could, of course, be made since the samples may be matched for any one of the variables studied. In order to limit the number of comparisons the length of femur_m has been chosen arbitrarily as reference.

Figure 4 depicts graphically the differences in stature and in the lengths of radius, humerus, and tibia among Whites and Negroes of both sexes of the Terry Collection matched for the length of femur$_m$. It is evident that the males of each race are taller than the females for a given length of femur, and that the Whites are taller than the Negroes. However, except for relatively short statures the White females are taller for a given length of femur than are the Negro males. Likewise, for the humerus, radius and tibia, the males have the longer bones relative to the length of femur, throughout the range of

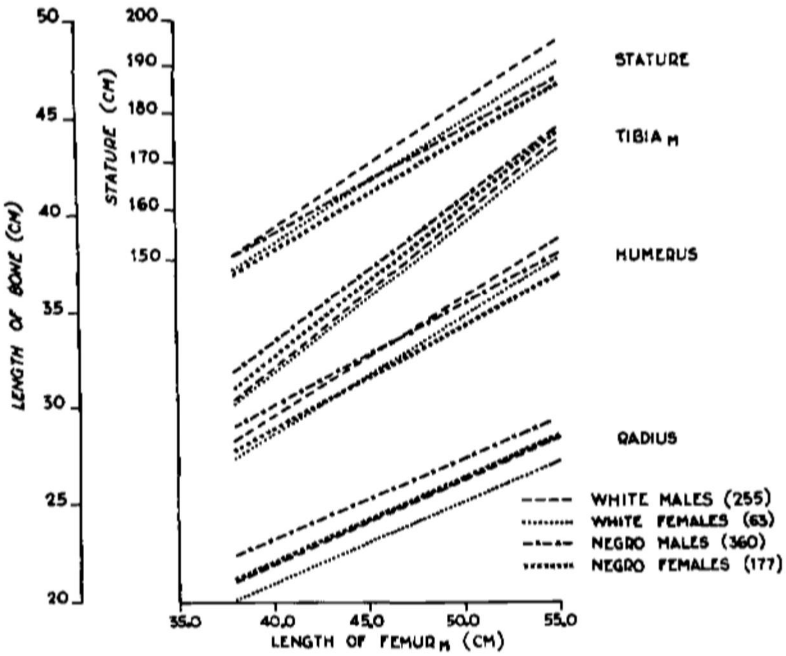

Fig. 4 Comparison of statures and lengths of long bones of Negroes and Whites of both sexes of the Terry Collection, matched for the length of the femur$_m$.

measurements. The Negro also has a longer tibia and radius relative to the femur than the White but the humerus of the Negro is longer than that of the White of corresponding sex only for those individuals with short femurs. These findings substantiate the conclusion generally reached that Negroes have longer forearms and legs relative to the more proximal segments of the limbs (arms and thighs) than do White individuals, and that, in general, Negroes have longer limb bones relative to their stature than do Whites. It is evident from figure 4 also that it is necessary for the sake of obtaining the most accurate estimates of stature to have different equations for each of the two sexes and for each of the two races.

A "general" equation or an average of the equations derived from different racial groups would necessarily result in poorer estimates of stature for any particular group or individual to which it is applied than would an equation derived from a similar group. However, if it is desired to estimate the *mean* stature of a mixed group for which the race and sex of each individual is indeterminate but for which there is *a priori* knowledge of the percentage frequency of the racial and sexual components, the most accurate result would be obtained by weighting the estimates derived from each equation according to the relative frequency of the races and/or sexes involved. And, if the stature of a single individual from such a mixed group were desired, the equation most likely to give the most accurate estimate is that pertaining to the race and sex most frequently represented in the group.

SUMMARY

The American Graves Registration Service has obligations which have stimulated interest in improvement of methods for identification of skeletal remains. Coincidentally, the ideal combination of data for the determination of formulae for estimation of stature from long bone lengths became available. These data are from American White and Negro military personnel and comprise measurements of stature during life and measurements of long bones of the free limbs after death. The Terry Anatomical Collection has been introduced into this study in order that formulae from a very different source might be provided; that these two sets of formulae, after adjustment for differences in age and in measurements of living and cadaver stature, might be tested against each other; and, that formulae for females of both races might be evolved.

Only subjects who were at least 18 years of age when stature was measured have afforded data for the equations of stature

estimation. All 6 long bones were measured for maximum length; in addition, the bicondylar length of the femur and the length between the articulating surfaces of the tibia were taken. The average length of right and left bones of any given pair was utilized in the statistics because of the greater reliability of an average. Furthermore, the differences in length between the bones of the two sides are small and when the bone of only one side is available an adjustment in an equation based on the average is not necessary.

Regression equations for estimation of stature from the length of each long bone and from the lengths of multiple bones were determined for each group of subjects available from the two sources. The single bone equations are almost identical for the two lengths of femur and for the two lengths of tibia; thus only the maximum length of each bone was utilized in the multiple bone equations. Intercorrelations among the lengths of the 6 long bones are very high, particularly between radius and ulna and between tibia and fibula, so the ulna and fibula were omitted in the multiple bone equations. In both single and multiple equations the bones of the lower limb result in estimations of stature with a smaller standard error than do the bones of the upper limb.

Equations for estimation of long bone lengths (humerus, radius, ulna, tibia, fibula) from the femur are presented for Whites and Negroes of both sexes.

The increase in cadaver stature (measured according to the method of Terry) over that of living stature is estimated to be 2.5 cm. When this correction is made and loss of stature from ageing is taken into account, the equations for estimation of stature of males based on data from the Terry Collection and from the military personnel are shown to be in substantial agreement. It seemed reasonable to assume that equations based on females of the Terry Collection, with corresponding adjustments are likewise applicable to the American population of White and Negro females.

Thus, equations (determined from both single and multiple bones) for estimation of living stature of American Whites and

Negroes of both sexes are presented. These equations are applicable to maximum lengths of long bones which are dry and without cartilage. The resultant estimates are of maximum living stature and can be reduced by the amount of 0.06 (age in years — 30) cm to cover the effects of ageing. A test of the equations for White males by application to a different sample of American White military personnel gives results well within the expected range of accuracy. Comparison of statures estimated for this new sample according to equations (involving femur and humerus) developed in this study with those of other investigators demonstrates that the present formulae give the most accurate estimates of stature. Another comparison involving the application of each investigator's equation (based on the femur) to every other sample of like sex demonstrates the advantage of the age factor in the equation and also the need for an adjustment when cadaver stature (as measured by Todd) is utilized as a measurement of living stature.

The Negroes of both sexes have significantly longer bones of the free limbs than do the White groups; the Negroes also have longer forearm and leg bones relative to the arm and thigh bones than do the Whites; and, in general the Negroes have longer bones of the limbs relative to their stature. These comparisons, pointed toward the relationship of the variables, indicate the necessity of independent equations for estimation of stature for each sex of the White and Negro races.

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