J Forensic Sci, July 2009, Vol. 54, No. 4
doi: 10.1111/j.1556-4029.2009.01048.x
Available online at: www.blackwell-synergy.com

Bradley J. Adams,[1] Ph.D. and Nicholas P. Herrmann,[2] Ph.D.

Estimation of Living Stature from Selected Anthropometric (Soft Tissue) Measurements: Applications for Forensic Anthropology

ABSTRACT: Estimation of living stature has obvious utility in the identification process. Typically, anthropologists estimate stature from the measurement of long bone length. This type of analysis is traditionally conducted on skeletonized or badly decomposed remains, so collection of the necessary bone measurements is relatively simple. As the role of anthropologists expands into medical examiner offices and mass fatality incidents, the analysis of fleshed bodies and body parts is a more common scenario. For stature estimation in these types of cases (e.g., analysis of body portions recovered from an aircraft crash site or from intentional dismemberment), the presence of soft tissue on the human remains would usually necessitate dissection to expose skeletal elements to derive metric data for stature estimation. In order to circumvent this step, this paper provides various formulae that allow for standard anthropometric (i.e., soft tissue) measurements to be used in place of skeletal measurements. Data were compiled from several anthropometric studies (National Health and Nutrition Examination Survey [NHANES] and U.S. Army Anthropometric Survey [ANSUR]) and numerous regression models are presented. Results are compared between skeletal measurements and the anthropometric measurements from each study. It was found that the ANSUR models are similar to the skeletal models, while the NHANES models exhibit weaker correlation coefficients and higher standard errors. Overall, this study finds that stature estimates derived from anthropometric data provide good results and remove the necessity for dissection when working with fleshed body portions.

KEYWORDS: forensic science, forensic anthropology, stature estimation, mass fatality, dismemberment, identification, NHANES, ANSUR

Estimation of living stature is one of the core components in a forensic anthropologist's analysis of unidentified remains. This information may be useful for decedent identification, especially when individuals are observed to be particularly tall or short in comparison with their associated population. As forensic anthropologists routinely work with skeletonized or badly decomposed bodies, the collection of osteometric data is generally very straightforward and stature estimation is often one of the easiest components to generate for the biological profile. When dealing with fleshed remains, the collection of osteometric data can be more challenging as there is the need for soft tissue dissection. One way to bypass this requirement would be the use of anthropometric (i.e., soft tissue) measurements for the estimation of living stature. This paper attempts to provide numerous regression models based on anthropometric data which may be useful for the estimation of living stature from fleshed body parts.

Historically, there have been two different approaches to the estimation of stature from skeletal remains: the anatomical method and the mathematical method (1). The anatomical methods derive stature estimates from numerous skeletal elements. One of the earliest proponents of the anatomical method was Dwight, who recommended that the skeleton should be meticulously rearticulated on a table using clay to account for soft tissue, resulting in a close approximation of living stature (1). This is obviously a very tedious process that requires considerable effort on the part of the analyst and completeness of the skeleton. A more straightforward variant of the anatomical method is that of Fully (2). Fully's anatomical technique uses a summation of measurements taken on the major elements, along with a correction value to account for cartilage and soft tissue. Stature estimates based on the anatomical method result in a single point estimate and they are not dependent on knowing the ancestry or sex of the individual. When feasible, stature estimates based on the anatomical method, especially Fully's method, have been shown to be the most reliable techniques available (3,4). Recently, Fully's technique has been revised by Raxter and colleagues (5,6) through better measurement definitions and an adjustment to the soft tissue correction value. The main problem with the anatomical technique is that it necessitates the presence of a relatively complete and well-preserved skeleton, something that is not always available in forensic contexts. Clearly its advantages include the accuracy of the estimates and the lack of sex or population effects.

The mathematical method, on the other hand, is not reliant on access to a complete skeleton. It uses linear regression to estimate stature from a single bone or multiple bones. Most frequently these estimates are derived from maximum length measurements of long bones that are input into appropriate regression models. Maximum length measurements of long bones have been shown to be straightforward and easy to measure (7), making stature estimation from complete long bones a highly replicable process that is not subject to significant interobserver error. One notable exception for skeletal measurements is the difficulty with measurements of the tibia (8,9).

Some early studies examining the relationship between long bone length and stature can be traced back to the French studies of Rollet and Manouvrier (1), but it was Pearson (10) who first applied linear regression to the estimation of stature from bone length. The relational tables of Manouvrier and the regression models of Pearson were derived from samples of French cadavers in the late 1800s, and these were the common standards in anthropological analyses in the U.S. until the seminal works of Trotter and

[1]Office of Chief Medical Examiner, 520 First Ave., New York, NY 10016.
[2]Department of Anthropology and Middle Eastern Cultures, Mississippi State University, Mississippi State, MS 39762.

Received 25 April 2008; and in revised form 17 Aug. 2008; accepted 21 Aug. 2008.

Gleser (11,12) provided more robust models applicable to the U.S. population. Since Trotter and Gleser's publications, regression models for stature estimation have been developed for a wide range of bones and bone fragments, thus providing anthropologists with numerous options depending on the composition of their case (e.g., 13–18).

Unlike the anatomical models, the regression (i.e., mathematical) models for stature estimation are usually dependent on knowing the sex and ancestry of the unidentified individual. Studies have shown that models developed for one population may not provide reliable estimates when applied to another population (e.g., 19,20). Inputting measurement data into the regression models will produce a point estimate (the predicted stature). In order to account for normal variation in the population, the associated standard error (SE) of the estimate should be used to report a prediction interval. Proper calculation of a prediction interval is addressed by Giles and Klepinger (21). Commonly, prediction intervals are reported at either the 90% or 95% level.

Most of the stature models (anatomical and mathematical) estimate living, or measured, stature. For many of the most frequently utilized models, the known stature of the subjects was based on cadaver height (e.g., Terry and Hamann-Todd Collections) or data derived from military records (e.g., WWII and Korean War dead). Studies have shown that people tend to misrepresent their true stature when self-reporting (22,23). For many forensic scenarios, antemortem stature is based on self-reported information (e.g., driver's license) or information provided by a friend or relative. There is clearly more error involved in these types of reference data as compared with measured data. For this reason, Ousley (24) differentiates "forensic" stature from "measured" stature. He suggests that appropriate models should be utilized that are dependent on the scenario at hand. For example, a missing U.S. soldier would likely have a measured stature in his or her medical records, while a routine medical examiner case might rely on less reliable antemortem information, such as a driver's license or missing person report. For the models presented in this paper, which are based on anthropometric measurements, the data are derived from "measured" stature of living subjects and this should be considered during their application to forensic casework.

Overview of Soft-Tissue Data

While most forensic anthropologists focus their analyses on skeletal data when deriving stature estimates, the incorporation of anthropometric (i.e., soft tissue) data into these estimates is a logical step for forensic applications and one that has been underutilized. Today, the role of the forensic anthropologist is not solely restricted to dry bones. For example, anthropologists play integral roles in the resolution of mass fatality events and medical examiner casework. More frequently than not, the decedents in these scenarios will still have soft tissue present. Certainly many types of anthropological analyses, such as an assessment of skeletal trauma, require dissection and maceration of soft tissue in order to allow a thorough evaluation, but this may not be necessary for the estimation of living stature.

Anthropology has a long history relating to the collection of metric data from living subjects (e.g., [25–27]), but its incorporation into the forensic arena has been limited. Generally, anthropometric data has been utilized as a gauge of a population's health and nutrition status, to understand body proportions for the design of clothing and equipment, and by medical personnel to estimate stature of the disabled.

Medical personnel may use anthropometric measurements in a clinical setting to estimate stature of the living (particularly, the elderly and disabled) who are not able to stand erect. Regression models are available in the published literature for these scenarios, many with very high correlations cited (e.g., [28–33]). Most of these regression equations use age as a variable in the formulae and are intended for use on the elderly. One notable exception is a study by Chumlea and colleagues (29) who utilized data from a series of national health surveys conducted between 1960 and 1970. From these data, they present regression models for estimating stature of white and black men and women (18–60 years) and boys and girls (6–18 years) from knee height. The models presented in this study for the men and children could be applied to forensic contexts, but the models for women incorporate age as a variable in the models. For other clinical models that incorporate age into their regression models, they are not readily applicable to most forensic scenarios. Obviously, patients in the clinical setting are of known age and the intent of the stature estimate is far different from the forensic context. For forensic investigations in which stature would need to be calculated, the identity of the decedent is unknown or tentative. To this end, it is not appropriate to use known age as a variable in the regression model because it may only be possible to provide a very general age estimate (especially in circumstances of body fragmentation).

Additional anthropometric studies have been conducted in order to evaluate the health and nutrition status of populations. One of the larger studies in the U.S. is the National Health and Nutrition Examination Survey which has been conducted periodically since the 1960s. Data, including anthropometric measurements, have been routinely collected from a representative sample of the population in order to track the country's health and nutrition status. Specifically, the National Health and Nutrition Examination Survey (NHANES) body measurement data are used to track the prevalence of obesity and to examine associations between body weight and the health and nutritional status of the U.S. population. These data are available via the internet from the Centers for Disease Control and Prevention and provide a valuable dataset for research.

Anthropometric studies have also been conducted in order to understand body proportions and dimensions. Some of the most ambitious anthropometric studies for this purpose have been undertaken on military personnel in order to fully understand the body sizes and proportions of active duty personnel. The anthropometric data are critical as a guide for the design and sizing of clothing, personal protective equipment, military weapon systems, and work stations (34). One of the most extensive studies was the U.S. Army Anthropometric Survey (ANSUR) conducted in 1987 and 1988. Close to 9000 subjects were measured and over 130 measurements were collected (34).

As noted previously, few studies have looked at the use of anthropometric data for forensic purposes. A few notable examples include Ozaslan and colleagues (35,36) and Attallah and Marshall (37). The studies of Ozaslan and colleagues were both based on a reference population of 202 males and 108 females from Istanbul, Turkey. One study focused on the measurements of the upper extremity, while the other dealt with several leg and foot measurements. In these studies, the authors found that living stature could be accurately estimated from body segments and they present regression models for estimation. The study of Attallah and Marshall focused on stature estimation from limb segments of children between the ages of 4 and 18 years. Their anthropometric sample was compiled in London and consists of 514 boys and 680 girls described as "western European origin." Numerous univariate and multivariate regression models are presented by the authors to estimate stature from subadult body measurements. Finally, there have been numerous studies that have explored the relationship between living statue and hand and foot length (e.g., [38–43]).

Materials and Methods

The goal of this paper is to provide numerous stature regression models derived from large samples of anthropometric data which are suitable for application within the U.S. Data from two large anthropometric studies have been published and are available for research. These include the NHANES study conducted by the National Center for Health Statistics and the ANSUR conducted by the U.S. Army Natick Research, Development, and Engineering Center.

NHANES Data 1999–2006

The NHANES has been an on-going study conducted by the National Center for Health Statistics (part of the Centers for Disease Control and Prevention) since the 1960s. The study group is composed of a large, representative sample of civilians (adults and children) from across the continental U.S. There are many components to the study, only one of which is anthropometric data collection. In order to develop regression models for the estimation of stature, a subsample of the NHANES data was extracted from studies conducted between 1999 and 2006. Only data pertaining to adults between the ages of 18 and 50 years were selected (n = 14,548). Table 1 presents the sample composition by sex and ancestry. Anthropometric variables utilized from the NHANES study were Standing Height, Upper Arm Length (UPARMLTH), and Upper Leg Length (UPLEGLTH). For the NHANES data, measurement values for the limb portions were recorded to the nearest 0.1 cm using a measuring tape. The NHANES measurements are described as follows (44):

1. Standing Height (i.e., STATURE) is the maximum vertical size from the bottom of the feet to the top of the head. The measurement is taken with a fixed stadiometer with a vertical backboard and a movable headboard.
2. UPARMLTH is measured with a tape measure. The upper most edge of the posterior border of the acromion process of the scapula is marked, and the tape measure is extended down the posterior surface of the arm to the tip of the olecranon process of the ulna. The measurement is taken with the arm flexed 90° (Fig. 1).
3. UPLEGLTH is taken while the subject is in a sitting position with the knee bent at 90°. The measurement is taken with a tape measure from the inguinal crease (just below the anterior superior iliac spine), along the anterior midline of the thigh, to the proximal patella (Fig. 1). The mark on the proximal patella is perhaps the most complicated landmark for this measurement and can be located by placing sliding calipers against the distal end of the femur, as though you were measuring the breadth of the patella. When positioning the calipers in this manner, a mark can be placed on the anterior surface of the thigh, along the horizontal bar of the calipers. This delineates the measurement point associated with the distal femur/proximal patella.

TABLE 1—*Population samples from the NHANES data (18–50 years of age).*

NHANES Samples	BM	BF	WM	WF	HM	HF	Total
1999–2000	607	688	1080	1279	954	1132	5740
2001–2002	343	371	619	735	475	524	3067
2003–2004	350	380	605	683	359	397	2774
2005–2006	379	420	571	665	425	507	2967
Total	1679	1859	2875	3362	2213	2560	14548

NHANES, National Health and Nutrition Examination Survey; BM, Black male; BF, Black female; WM, White male; WF, White female; HM, Hispanic male; HF, Hispanic female.

ANSUR Natick Data 1987–1988

In order to complement the NHANES data and account for additional scenarios involving fragmentary/dismembered body portions, additional models based on anthropometric studies of active duty U.S. Army personnel are reproduced from the ANSUR report conducted by the U.S. Army Natick Research, Development, and Engineering Center (Technical Report Natick/TR-90/035). This study was based on data compiled from active duty Army personnel in 1987 and 1988 (34). A follow-up study in 1996 showed that this data was still representative of the U.S. Army population in 1996 (45). Although the ANSUR anthropometric survey consisted of nearly 9000 individuals, the published results are based on the "working database," which was selected to represent the various age and race groups representative of the U.S. Army in 1988 (34). The working database consisted of 3982 individuals between 17 and 51 years of age. Table 2 presents the sample composition by sex and ancestry. The summary statistics and published regression models are divided by sex, but all of the racial groups have been pooled as part of the original study (46). Formulae for the ANSUR data were published in the Natick summary reports and several are reproduced here for comparative purposes. The variables selected for possible forensic application include: Stature (STATURE), Buttock-Knee Length (BUTTKLTH), Forearm-Hand Length (FORHDLG), Knee Height-Sitting (KNEEHTSI), Shoulder-Elbow Length (SHOUELLT), Lateral Femoral Epicondyle Height (LATFEMEP), Span (SPAN), Foot Length (FOOTLGTH), and Hand Length (HANDLGTH). For the ANSUR data, the measurements are all taken with calipers or anthropometers and are described as follows (34):

1. STATURE is the vertical distance from a standing surface to the top of the head. The subject stands erect with the head in the Frankfort plane and the measurement is taken with an anthropometer.
2. BUTTKLTH is the horizontal distance between the most posterior point on the buttock and the anterior point of the knee measured while the knee is flexed 90° (Fig. 1). This measurement is taken along the lateral thigh with an anthropometer.
3. FOOTLGTH is the maximum length of the foot from the heel to the tip of the longest toe measured with calipers (Fig. 1).
4. FORHDLG is the horizontal distance between the posterior surface of the elbow and the tip of the middle finger taken while the elbow is flexed 90° (Fig. 1). It should be measured with a caliper.
5. HANDLGTH is the distance from the stylion landmark (the tip of the styloid process of the radius) to the tip of the middle finger, measured with a caliper (Fig. 1).
6. KNEEHTSI is the vertical distance between the bottom of the foot and the suprapatellar landmark (Fig. 1). The suprapatellar landmark is the superior surface of the patella and should be marked while the leg is in a standing position. The overall Knee Height measurement, however, is taken with the knee flexed 90°, measured with an anthropometer.
7. SHOUELLT is the distance between the acromion landmark (superior tip of the acromion process) of the shoulder and the olecranon landmark on the bottom of the elbow (Fig. 1). The

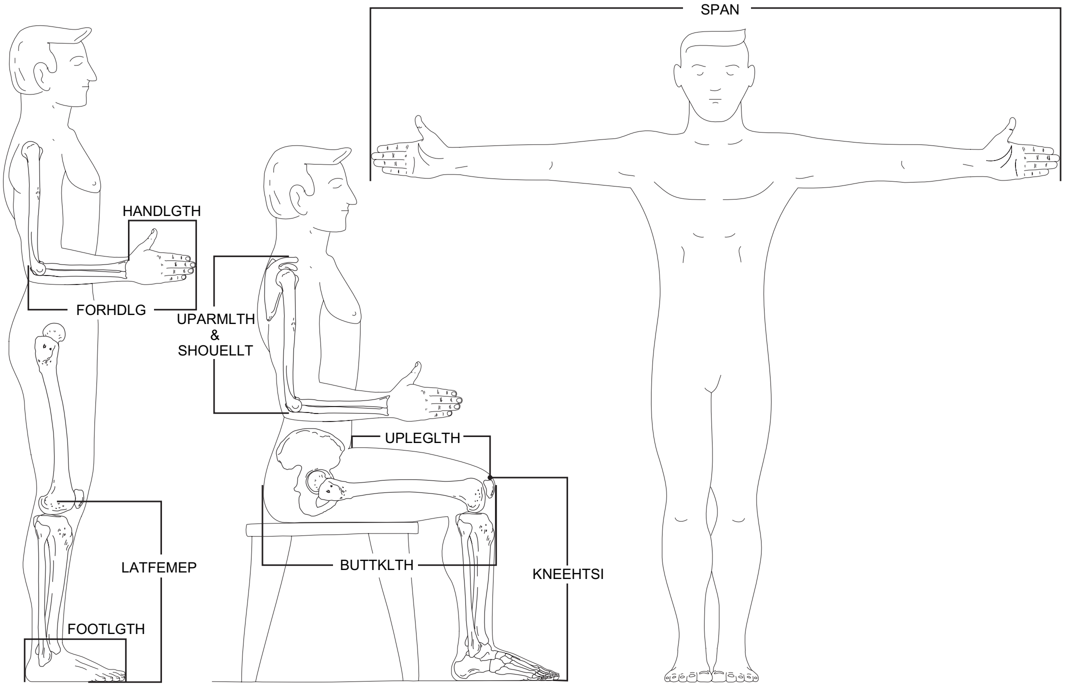

FIG. 1—*Anthropmetric measurements examined from U.S. Army Anthropometric Survey (ANSUR) and National Health and Nutrition Examination Survey (NHANES).*

TABLE 2—*Population samples from the ANSUR data.*

ANSUR Samples 1987–1988	White	Black	Hispanic	Asian/ Pacific	American-Indian	Other	Total
Male	1172	458	68	28	12	36	1774
Female	1140	922	58	32	14	42	2208
Total	2312	1380	126	60	26	78	3982

measurement should be taken while the elbow is flexed 90° and measured with a caliper. Note that UPARMLTH in the NHANES study utilizes the same landmarks, but the NHANES measurement is taken with a measuring tape.

8. LATFEMEP is the vertical distance between the bottom of the foot and the lateral femoral epicondyle (most laterally projecting point on the lateral femoral condyle at the knee pivot point). The measurement is taken with an anthropometer while the leg is in a standing position (Fig. 1).
9. SPAN is the distance between the tips of the middle fingers when the arms are horizontally outstretched (Fig. 1). For living subjects, this is taken while the subject is standing against a measured wall chart. Although not formally tested, it is hypothesized that an anthropometer may provide a comparable measurement.

Results

Using the NHANES data, it was possible to construct anthropometric regression equations for stature estimation. Models were derived for White, Black, and Hispanic groups by sex. In addition, models are presented for circumstances when ancestry and/or sex are unknown. The regression models are presented in Table 3. In addition, numerous regression models using the selected measures derived from the ANSUR study are presented in Table 4. Note that

TABLE 3—*Regression coefficients for stature estimation from UPARMLTH and UPLEGLTH measurements from the NHANES data (1999–2006).*

	n	Intercept	Slope	Error	*r*
UPARMLTH					
All (unknown sex and group)	14,540	61.27	2.88	6.04	0.80
Sex (group unknown)					
Male	6763	83.25	2.38	5.56	0.72
Female	7777	88.80	2.05	5.20	0.66
Group (sex unknown)					
White	6235	65.68	2.81	5.84	0.79
Black	3535	66.84	2.72	6.36	0.76
Hispanic	4770	60.26	2.87	5.53	0.80
Group and sex known					
White male	2873	95.87	2.10	5.30	0.66
White female	3362	97.02	1.88	4.91	0.62
Black male	1677	98.48	2.00	5.34	0.67
Black female	1858	100.65	1.72	5.01	0.61
Hispanic male	2213	83.71	2.31	5.13	0.71
Hispanic female	2557	84.91	2.11	4.74	0.66
UPLEGLTH					
All (unknown sex and group)	14,350	85.56	2.02	6.51	0.76
Sex (group unknown)					
Male	6680	103.77	1.67	5.77	0.69
Female	7670	109.85	1.34	5.45	0.61
Group (sex unknown)					
White	6169	86.03	2.05	6.37	0.74
Black	3483	84.18	2.02	6.58	0.74
Hispanic	4698	87.74	1.94	6.04	0.75
Group and sex known					
White male	2849	115.26	1.45	5.55	0.61
White female	3320	114.02	1.28	5.19	0.56
Black male	1656	105.83	1.61	5.35	0.67
Black female	1827	118.24	1.11	5.26	0.55
Hispanic male	2175	105.58	1.57	5.41	0.67
Hispanic female	2523	109.88	1.28	5.03	0.61

UPLEGLTH, upper leg length; UPARMLTH, upper arm length; NHANES, National Health and Nutrition Examination Survey.

All measurements in cm.

TABLE 4—*Regression coefficients for stature estimation from various measurements from the U.S. Army ANSUR data (1987–1988).*

	Intercept	Slope	Error	*r*
Males, *n* = 1774				
BUTTKLTH	64.94	1.80	3.99	0.80
FOOTLGTH	79.24	3.57	4.77	0.70
FORHDLG	71.70	2.15	4.43	0.75
HANDLGTH	89.58	4.44	5.08	0.65
KNEEHTSI	57.17	2.12	3.11	0.89
LATFEMEP	64.69	2.21	3.30	0.87
SHOUELLT	63.10	3.05	3.84	0.82
SPAN	54.45	0.66	3.87	0.83
Females, *n* = 2208				
BUTTKLTH	68.91	1.60	4.25	0.74
FOOTLGTH	77.40	3.50	4.71	0.67
FORHDLG	77.14	1.94	4.47	0.71
HANDLGTH	87.58	4.18	4.91	0.64
KNEEHTSI	56.23	2.07	3.28	0.86
LATFEMEP	62.36	2.18	3.37	0.85
SHOUELLT	64.97	2.92	3.83	0.80
SPAN	59.92	0.62	3.92	0.79

ANSUR, Anthropometric Survey; BUTTKLTH, Buttock-Knee Length; FOOTLGTH, foot length; FORHDLG, forearm-hand length; HANDLGTH, hand length; KNEEHTSI, Knee Height-Sitting; LATFEMEP, Lateral Femoral Epicondyle Height; SHOUELLT, Shoulder-Elbow Length.

All measurements in cm.

the raw ANSUR data were not available for reanalysis and the models presented require that sex is known.

In order to observe the difference between models derived from anthropometric measurement data and models derived from long bone length, it was possible to compare the results from the NHANES and ANSUR data with data presented by Trotter and Gleser (12). Table 5 presents the correlation values between stature and maximum lengths of the humerus and femur from Trotter and Gleser's data. Although the anthropometric data does not correspond precisely to these bones, the models for the upper arm and leg are comparable. For the NHANES data, the correlations and SE of UPARMLTH and UPLEGLTH can be compared. For the ANSUR data, these can be compared with BUTTKLTH and SHOUELLT.

When comparing Trotter and Gleser's 1958 Korean War data for the humerus (Table 5) to the NHANES model for UPARMLTH (Table 3), it is clear that the long bone measurements are more strongly correlated with stature than the corresponding soft tissue models. For the NHANES anthropometric data, the correlation (*r*-values) for White male (WM) = 0.66 and for Black male (BM) = 0.67. For Trotter and Gleser's osteometric data, the correlation for WM = 0.73 and for BM = 0.76. When comparing the SE of the estimate values, the NHANES figures for WM = 5.30 and BM = 5.34, while the Trotter and Gleser values are lower with WM = 4.61 and BM = 4.26.

Interestingly, when the most comparable data is observed from the ANSUR sample (pooled males) for SHOUELLT (Table 4), the anthropometric data has a higher *r*-value and a lower SE than the osteometric data. For the ANSUR anthropometric data, the correlation for SHOUELLT = 0.82 and the SE is 3.84. This would suggest that the ANSUR model outperforms the osteometric model of Trotter and Gleser.

TABLE 5—*Correlation (r) and SE values of humerus and femur with stature in 18- to 46-year-old males from the Korean War (12: Table 3).*

	White		Black	
	r	SE	*r*	SE
Humerus*	0.73	4.61	0.76	4.26
Femur*	0.80	4.04	0.81	3.83

SE, standard error.

*Values represent the right side only.

When comparing the data for the upper leg, the results are comparable with the arm. Comparison of the NHANES model for UPLEGLTH (Table 3) reveals an *r*-value of 0.61 for WM and an *r*-value of 0.67 for BM. The NHANES values for the SE are 5.55 for WM and 5.35 for BM. The Trotter and Gleser correlation values for Femur Length are considerably higher (Table 5), with values of 0.80 for WM and 0.81 for BM. Trotter and Gleser's error values are also lower, with 4.04 reported for WM and 3.83 reported for BM. The ANSUR data for pooled males and BUTTKLTH (Table 4) reveals an *r*-value of 0.80 and a SE of 3.99, both of which are nearly identical to the osteometric values reported by Trotter and Gleser.

To illustrate the correlation differential between osteological and soft tissue measures, plots of the NHANES data and a combined skeletal sample from Trotter's Terry and World War II data are presented in Figs. 2 and 3. Figure 2 pertains to UPLEGLTH and shows the relationship of WM from NHANES and Trotter's bone samples. In this example, bone length relative to stature produces a stronger correlation. The distribution of the NHANES UPLEGLTH relative to stature is far more dispersed. Similarly, the comparison of Trotter's humerus length data to NHANES UPARMLTH data show the same relationship (Fig. 3). It is also apparent that the NHANES UPARMLTH correlation with stature is stronger than the UPLEGLTH. In both cases, the NHANES fit lines roughly parallel the bone models and suggest a similar relationship to stature albeit shifted up or down along the y-axis. Although not graphically plotted, the ANSUR anthropometric data are more consistent with the skeletal data and provide tighter prediction models than seen with the NHANES sample.

Initially, it may seem unusual that the anthropometric studies provide such divergent results for very comparable measurements. This could be an indication that there are population differences between the NHANES (civilian) sample and the ANSUR (military) sample, even though the demographic composition is similar. A comparison of the ANSUR and NHANES distributions by sex finds that the means are very similar, although there are differences between the samples. The basic statistics by sex for both samples are presented in Table 6. Overall, male mean stature in the two

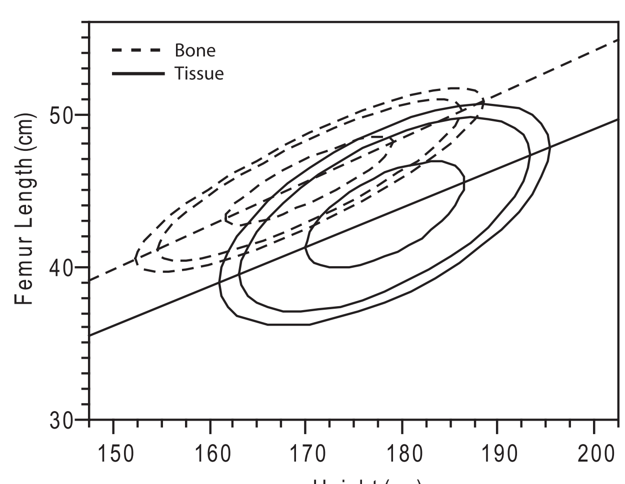

FIG. 2—*Comparison of upper leg and femur length from NHANES and Trotter's World War II and Terry Collection measures for White males.*

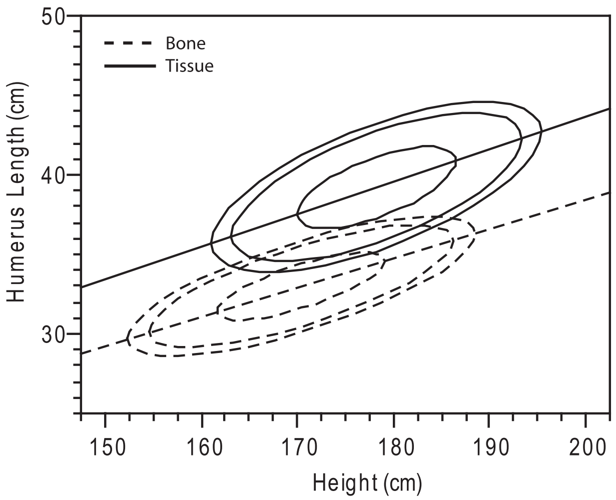

FIG. 3—*Comparison of upper arm and humerus length from NHANES and Trotter's World War II and Terry Collection measures for White males.*

samples is not significantly different ($t = 0.118$, $p = 0.906$, d.f. = 3228). The female means differ by less than one centimeter; however, this difference is statistically significant ($t = 4.955$, $p < 0.0001$, d.f. = 3801). These distributions of the two samples are plotted in Fig. 4. The ANSUR sample for both males and females does appear more tightly clustered around the mean and this observation is supported by the smaller standard deviations (SD) in the ANSUR samples as compared with NHANES. It is suspected that lower variation in overall stature in the ANSUR sample may be one contributing factor to the higher correlation reported in the study.

While there is validity to this assertion, another likely hypothesis for the difference may simply be related to the methods of measurement involved in each study. As pointed out by Gordon and colleagues ([34], p. 623) in their discussion of the ANSUR study, "Differences in landmark definitions, subject positioning, instruments and their techniques of use can and do lead to significantly different results." For the NHANES study, the measurements were taken with a tape measure extended between specific landmarks. The ANSUR data, on the other hand, were all collected with anthropometers or calipers. It is suspected that the use of calipers in the data collection process provides more precise values that are more closely related to actual skeletal dimensions. When tape measures are utilized, Body Mass Index (BMI) may have an effect on the overall measurement. For example, a person with a high BMI will have more adipose tissue, which may artificially inflate the length measurement if a tape is extended along the soft tissue of the arm or leg.

TABLE 6—*NHANES and ANSUR sample statistics by sex.*

	Samples	
Sex	NHANES	ANSUR
Males		
n	6767	1774
Mean	175.60	175.58
SD	7.98	6.68
Kurtosis	0.02	3.09
CV	4.54	3.80
Females		
n	7781	2208
Mean	162.17	162.94
SD	6.89	6.36
Kurtosis	0.08	3.01
CV	4.25	3.90

NHANES, National Health and Nutrition Examination Survey; ANSUR, Anthropometric Survey; SD, standard deviation; CV, coefficient of variation.

BMI is a variable that is present within the NHANES dataset, which allowed for the opportunity to test this theory. The strength of correlation (*r*-values) was explored for UPLEGLTH and UPARMLTH according to the participants' BMI. Table 7 shows that the heaviest individuals (BMI > 30) have the lowest correlation with Standing Height. One of the NHANES manuals provides confirmation of this supposition. It states, "Analysts should examine the distributions of the body measurements carefully. In particular, the upper arm length…and upper leg length…values are affected by extreme amounts of adipose tissue" ([47], p. 3).

Recommendations and Conclusions

For this paper, large datasets of anthropometric data were analyzed or reviewed in order to present regression models that could be useful for the forensic scientist in the estimation of living stature from fragmentary bodies. It is anticipated that these formulae may be applicable to mass fatality incidents resulting in body fragmentation (e.g., aircraft crashes) or in cases of intentional body dismemberment. These models are presented in Tables 3 and 4 and they contain the appropriate values to calculate stature estimates from various body segments. For the NHANES data, numerous options are made available depending on the case parameters, such as knowledge of the decedent's sex or ancestry. For the ANSUR data, only sex-specific models are available. Because of the very large sample sizes in both the NHANES and the ANSUR studies, it is very straightforward to calculate a point estimate and the associated confidence intervals from the presented models.

For example, take a scenario where portions of a dismembered male body are discovered. There is a right leg present from the proximal femur to the foot. An appropriate measurement to use would be the LATFEMEP from the ANSUR data (note that this measurement should be taken with calipers). The regression model is:

$$\mathrm{STATURE} = \mathrm{LATFEMEP}(2.21) + 64.69$$

Assuming that the measurement is 56.0 cm, the resulting point estimate for the individual's stature would be 188.45 cm, or 74.2 inches. Because of the large sample sizes associated with both the NHANES and ANSUR data, it is possible to derive a prediction interval directly from the SE of the estimate. For a 90% prediction interval, simply multiply the SE of the estimate, in this case 3.30, by 1.645. For a 95% prediction interval, the error value should be multiplied by 1.96. Adding and subtracting the result to the point estimate will provide the desired prediction interval. In this example, the 90% prediction interval would be 183.05–193.85 cm (72.1–76.3 inches).

As shown in this paper, there appears to be a marked difference in the anthropometric regression models which we believe is based largely on the type of measurement equipment utilized in the data collection process. The NHANES data were collected with a tape measure that was extended along the body, while the ANSUR data was collected with calipers. It is apparent that BMI does have an effect on the NHANES data, likely skewing measurements when significant amounts of adipose tissue are present. Another contributing factor may be the sample compositions of the NHANES and ANSUR studies. For the NHANES group, there appears to be greater dispersion around the sample's mean stature (indicated by the higher SD and coefficient of variation [CV] values) than

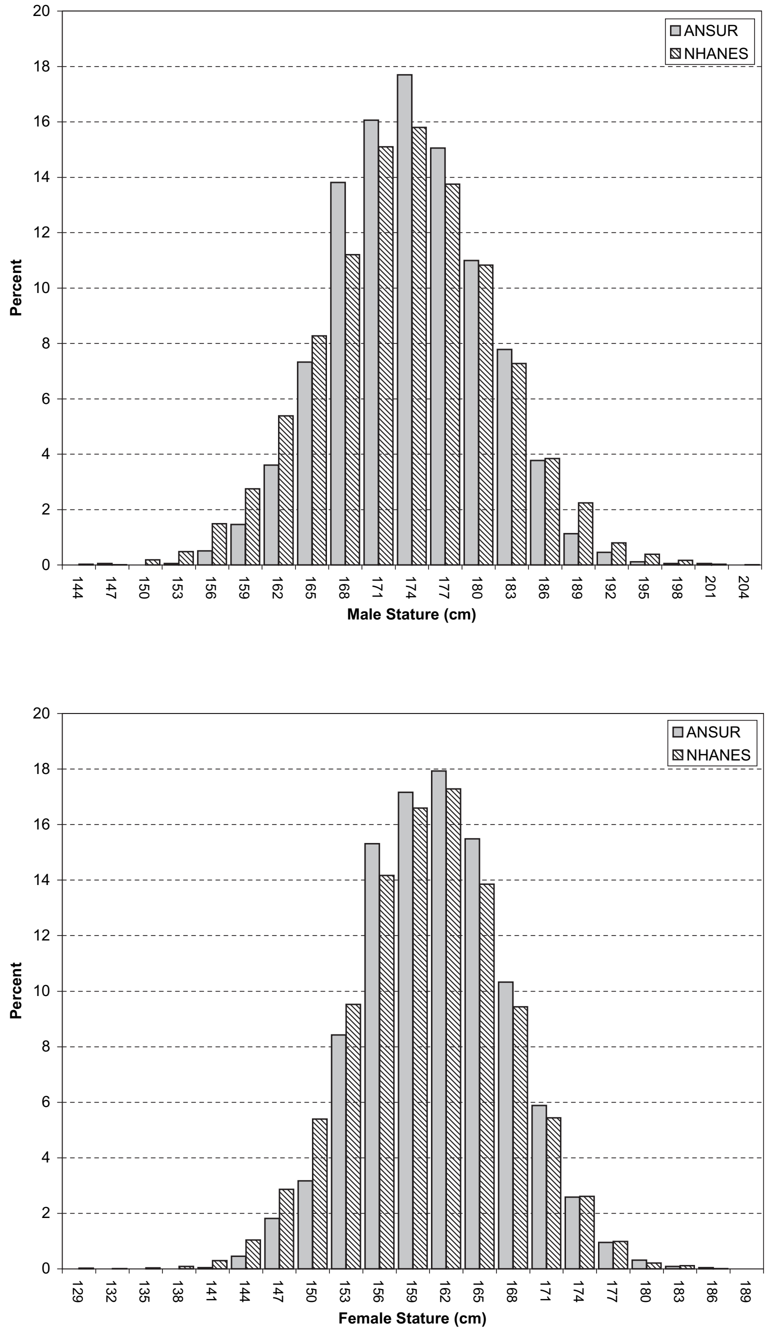

FIG. 4—*Distribution of NHANES and ANSUR statures for males and females.*

TABLE 7—*BMI correlations for UPARMLTH and UPLEGLTH from the NHANES data.*

	BMI Correlations (*n*)			
Limb	<20	20–25	25–30	>30
UPARMLTH				
Male	0.749 (456)	0.741 (2249)	0.748 (2451)	0.713 (1700)
Female	0.713 (674)	0.722 (2336)	0.713 (2198)	0.691 (2662)
UPLEGLTH				
Male	0.722 (426)	0.716 (2213)	0.689 (2410)	0.650 (1652)
Female	0.606 (652)	0.663 (2302)	0.671 (2163)	0.539 (2586)

BMI, Body Mass Index; NHANES, National Health and Nutrition Examination Survey; UPARMLTH, upper arm length; UPLEGLTH, upper leg length.

observed with the ANSUR group. This suggests that there is greater variability in stature among the NHANES participants.

Based on the results of this study, anthropometric measurements of certain body portions are suitable for the estimation of living stature and are applicable to forensic contexts within the U.S. Use of these regression models removes the need for soft tissue dissection in order to obtain skeletal measurements. While radiographic alternatives may also be feasible for stature estimation of fleshed remains, the use of the anthropometric techniques presented in this paper is an expedient option (simply relies on the use of calipers or a tape measure) and provides results of comparable accuracy to skeletal techniques. Numerous stature estimation formulae are presented based on the NHANES and ANSUR anthropometric data. Although the NHANES models do not perform as well as comparable osteometric equations, the ANSUR models meet or exceed the skeletal models. For this reason, it is encouraged that anthropometers and calipers should be used along with the ANSUR models if feasible. The NHANES models will still provide useful information if access to the proper instrumentation is not possible or for situations in which sex is unknown. If the NHANES models are to be utilized, the measurements should be taken with a tape measure.

Acknowledgments

The authors would like to thank the Ellis R. Kerley Forensic Sciences Foundation for their recognition of the importance of this research. The authors would also like to thank the numerous individuals who took an interest in this project, including Frank and Julie Saul, P. Willey, and John Byrd. The authors would like to acknowledge Chris Rainwater for creating the anatomical figures.

References

1. Stewart TD. Essentials of forensic anthropology. Springfield, IL: Charles C. Thomas, 1979.
2. Fully G. Une nouvelle méthode de détermination de la. taille. Ann Med Legale 1956;35:266–73.
3. Lundy JK. The mathematical versus anatomical methods of stature estimate from long bones. Am J Forensic Med Pathol 1985;6(1):73–6.
4. Lundy JK. A report on the use of Fully's anatomical method to estimate stature in military skeletal remains. J Forensic Sci 1988;33(2):534–9.
5. Raxter MH, Auerbach BM, Ruff CB. Revision of the Fully technique for estimating statures. Am J Phys Anthropol 2006;130(3):374–84.
6. Raxter MH, Ruff CB, Auerbach BM. Technical note: revised fully stature estimation technique. Am J Phys Anthropol 2007;133(2):817–8.
7. Adams BJ, Byrd JE. Interobserver variation of selected postcranial skeletal measurements. J Forensic Sci 2002;47(6):1193–202.
8. Jantz RL, Hunt DR, Meadows L. Maximum length of the tibia: how did Trotter measure it? Am J Phys Anthropol 1994;93(4):525–8.
9. Jantz RL, Hunt DR, Meadows L. The measure and mismeasure of the tibia: implications for stature estimation. J Forensic Sci 1995;40(5):758–61.
10. Pearson K. Mathematical contributions to the theory of evolution. V. On the reconstruction of the stature of prehistoric races. Philos Trans R Soc Lond 1899;192:169–244.
11. Trotter M, Gleser GC. Estimation of stature from long bones of American whites and Negroes. Am J Phys Anthropol 1952;10:463–514.
12. Trotter M, Gleser GC. A re-evaluation of estimation of stature based on measurements of stature taken during life and of long bones after death. Am J Phys Anthropol 1958;16:79–123.
13. Byers S, Akoshima K, Curran B. Determination of adult stature from metatarsal length. Am J Phys Anthropol 1989;79(3):275–9.
14. Holland TD. Estimation of adult stature from fragmentary tibias. J Forensic Sci 1992;37(5):1223–9.
15. Meadows L, Jantz RL. Estimation of stature from metacarpal lengths. J Forensic Sci 1992;37(1):147–54.
16. Simmons T, Jantz RL, Bass WM. Stature estimation from fragmentary femora: a revision of the Steele method. J Forensic Sci 1990;35(3):628–36.
17. Steele D. Estimation of stature from fragments of long limb bones. In: Stewart T, editor. Personal identification in mass disasters. Washington, DC: National Museum of Natural History, 1970;85–97.
18. Steele DG, Bramblett CA. The anatomy and biology of the human skeleton. College Station, TX: Texas A&M University Press, 1998.
19. Ross AH, Konigsberg LW. New formulae for estimating stature in the Balkans. J Forensic Sci 2002;47(1):165–7.
20. Konigsberg LW, Hens SM, Jantz LM, Jungers WL. Stature estimation and calibration: Bayesian and maximum likelihood perspectives in physical anthropology. Am J Phys Anthropol 1998;27(Suppl. 27): 65–92.
21. Giles E, Klepinger LL. Confidence intervals for estimates based on linear regression in forensic anthropology. J Forensic Sci 1988;33(5):1218–22.
22. Giles E, Hutchinson DL. Stature- and age-related bias in self-reported stature. J Forensic Sci 1991;36(3):765–80.
23. Willey P, Falsetti T. Inaccuracy of height information on driver's licenses. J Forensic Sci 1991;36(3):813–9.
24. Ousley SD. Should we estimate biological or forensic stature? J Forensic Sci 1995;40(5):768–73.
25. Hrdlicka A. Anthropometry. Philadelphia, PA: Wistar Institute of Antatomy and Biology, 1920.
26. Boas F. Remarks on the theory of anthropometry. Publications of the American Statistical Association 1893;3(24):569–75.
27. Boas F. Report on an anthropometric investigation of the population of the United States. Race, Language and Culture. New York, NY: Macmillan, 1940. 28–59.
28. Chumlea WC, Guo S. Equations for predicting stature in white and black elderly individuals. J Gerontol 1992;47(6):197–203.
29. Chumlea WC, Guo SS, Steinbaugh ML. Prediction of stature from knee height for black and white adults and children with application to mobility-impaired or handicapped persons. J Am Diet Assoc 1994; 94(12):1385–91.
30. Chumlea WC, Roche AF, Steinbaugh ML. Estimating stature from knee height for persons 60 to 90 years of age. J Am Geriatr Soc 1985; 33(2):116–20.
31. Han TS, Lean ME. Lower leg length as an index of stature in adults. Int J Obes Relat Metab Disord 1996;20(1):21–7.
32. Johnson RK, Ferrara MS. Estimating stature from knee height for persons with cerebral palsy: an evaluation of estimation equations. J Am Diet Assoc 1991;91(10):1283–4.
33. Prothro JW, Rosenbloom CA. Physical measurements in an elderly black population: knee height as the dominant indicator of stature. J Gerontol 1993;48(1):15–8.
34. Gordon CC, Churchill T, Clauser CE, Bradtmiller B, McConville JT, Tebbetts I, et al. 1988 anthropometric survey of U.S. army personnel: methods and summary statistics. Technical Report NATICK/TR-89/044. Natick, MA: U.S. Army Natick Research, Development, and Engineering Center, 1989.
35. Ozaslan A, Iscan MY, Ozaslan I, Tugcu H, Koc S. Estimation of stature from body parts. Forensic Sci Int 2003;132(1):40–5.
36. Ozaslan A, Koc S, Ozaslan I, Tugcu H. Estimation of stature from upper extremity. Mil Med 2006;171(4):288–91.
37. Attallah NL, Marshall WA. The estimation of stature from anthropometric and photogrammetric measurements of the limbs. Med Sci Law 1986;26(1):53–9.
38. Agnihotri AK, Purwar B, Googoolye K, Agnihotri S, Jeebun N. Estimation of stature by foot length. J Forensic Leg Med 2007;14(5):279–83.
39. Giles E, Vallandigham PH. Height estimation from foot and shoeprint length. J Forensic Sci 1991;36(4):1134–51.
40. Gordon CC, Buikstra JE. Linear models for the prediction of stature from foot and boot dimensions. J Forensic Sci 1992;37(3):771–82.
41. Krishan K, Sharma A. Estimation of stature from dimensions of hands and feet in a North Indian population. J Forensic Leg Med 2007; 14(6):327–32.
42. Ozden H, Balci Y, Demirustu C, Turgut A, Ertugrul M. Stature and sex estimate using foot and shoe dimensions. Forensic Sci Int 2005;147(2-3):181–4.
43. Sanli SG, Kizilkanat ED, Boyan N, Ozsahin ET, Bozkir MG, Soames R, et al. Stature estimation based on hand length and foot length. Clin Anat 2005;18(8):589–96.
44. Anthropometry and physical activity monitor procedures manual: National Health and Nutrition Examination Survey, 2005. Available at: http://www.cdc.gov/nchs/data/nhanes/nhanes_05_06/BM.pdf.
45. Gordon CC. U.S. Army anthropometric survey database: downsizing, demographic change, and validity of the 1988 data in 1996. Natick, MA: Army Natick Research, Development, and Engineering Center, 1996.
46. Cheverud J, Gordon CC, Walker RA, Jacquish C, Kohn L, Moore A, et al. 1988 anthropometric survey of US army personnel: correlation coefficients and regression equations. Part 4. Bivariate regression tables. Technical Report NATICK/TR-90/035. Natick, MA: United States Army Natick Research, Development, and Engineering Center, 1990.
47. Documentation, codebook, and frequencies: body measurements—National Health and Nutrition Examination Survey 2005–2006, 2007. Available at: http://www.cdc.gov/nchs/data/nhanes/nhanes_05_06/bmx_d.pdf

Additional information:
Bradley J. Adams, Ph.D.
Forensic Anthropologist
Office of Chief Medical Examiner
520 First Ave.
New York, NY 10016
E-mail: badams@ocme.nyc.gov