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Estimation of Stature From Metacarpal Lengths

Lee Meadows
University of Tennessee, Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Lee Meadows entitled "Estimation of Stature From Metacarpal Lengths." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Anthropology.

William M. Bass, Major Professor

We have read this thesis and recommend its acceptance:

R.L. Jantz, P.S. Willey

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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ESTIMATION OF STATURE FROM METACARPAL LENGTHS

A Thesis

Presented for the

Master of Arts

Degree

The University of Tennessee, Knoxville

Lee Meadows

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ABSTRACT

Stature reconstruction is an important feature of any skeletal analysis including population studies, early hominid research, and personal identification. In 1978, Musgrave and Harneja provided formulae for the estimation of stature using metacarpal lengths. The sample in that study included white males and females, predominantly of British origin who had an injured hand presented for radiography. The study did not include both hands from the same individual, only the injured hand. In facing a human identification case involving only a partial hand, these formulae were applied. A test of Musgrave and Harneja (1978) stature formulae was conducted on known skeletons and found to be lacking. As a result of that case, a new study was deemed necessary based on modern Americans including whites and blacks of both genders. Formulae for the estimation of stature based on metacarpal lengths are presented. Two measurements are taken on all ten metacarpals of 212 (56 white males, 48 white females, 53 black males, 55 black females) individuals with known stature from the Terry Collection. A modern sample included radiographs of both left and right hands of 55 males (25 white, 30 black) of known stature. The strength of the

relationship between metacarpal length and stature is determined for both the Terry Collection sample and the modern sample. Bone length is regressed on stature to estimate equations for stature estimation for the Terry Collection.

Analysis of variance is employed to test for equality of slopes and adjusted means between the Terry Collection males and the modern sample. The variables that are not significantly different in slopes and adjusted means allow pooling of the Terry Collection males with the modern male sample. New equations for males stature estimation are derived and presented. The equations based on the Terry Collection females can be used with caution for the estimations of stature in a modern female population.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The estimation of stature has been examined by many researchers over the past century. Just as age, sex, and race estimates are important for population studies and personal identifications, stature is employed as well. Health and disease, nutrition, and even social status among populations are also reflected through statures. While living populations are studied with regard to stature, past populations are also of interest in this area of study. Unfortunately, past populations, in particular prehistoric populations, do not have records of statures during life, but have only information the skeleton can reflect. On occasion, statures are measured on skeletons during excavations if the bodies are in a supine or extended position (Neumann and Waldman, 1967; Boldsen, 1984).

While skeletons are available as the only tool for estimation of stature among prehistoric populations, modern populations have living heights for reference. Known stature can be regressed on the bone length to develop formulae for stature estimation. Various bones and combinations of bones of the human skeleton have been used in stature estimation methods on many different populations.

These modern techniques are of great value in the forensic setting .

Personal identification of human remains begins by the estimation of age, sex, and race of the individual. An important factor in this initial analysis is the estimation of stature of the individual. The methods employed in the stature estimation depend largely on the skeletal elements present as well as the sex and race estimates. Age can also be a factor in height estimates (Trotter and Gleser, 1951a; Galloway, 1988).

Many studies have been conducted on the estimation of stature using long limb bones, vertebrae, and even hand and foot bones. The present study focuses on the relationship between the lengths of metacarpals and stature. Both left and right hands are employed as significant differences occur between them. Musgrave and Harneja (1978) report on this topic, however, their sample includes radiographs of one hand each for 166 white living individuals (120 males and 46 females). The sample was obtained from individuals that had an injury to a hand requiring radiography.

The need for a more comprehensive study was evident, and thus this study was initiated. The sample size is larger for white males and females and includes black males and females. The measurements are taken on bone contrasted to the radiographs of Musgrave and Harneja (1978). Due to the lack of large modern skeletal samples, the Terry Collection

was used. A small modern sample was obtained for comparative purposes through radiography of both left and right noninjured hands of cadavers.

CHAPTER II

LITERATURE REVIEW

Reconstruction of stature from the skeleton has always been of interest to those studying human populations whether it be early hominids (Burns, 1971) or modern skeletons. Stature can reflect a variety of information such as sexual dimorphism (Eveleth, 1975; Gray and Wolfe, 1980; Hiernaux, 1968), health and nutrition status (Nickens,1976; Hardy, 1938), genetic composition and environment (Kaplan, 1954; Johnston et al., 1976; Wolanski and Kasprzak, 1976), and even social status as well as evolution as seen in secular trends (c.f. Trotter and Gleser, 1951a; Cannon, 1986). The problem has been in the lack of known living heights of individuals, and the statures have had to be estimated using the skeletal elements such as the long limb bones, vertebrae, hand and foot bones, and combinations of these. Many studies have been conducted soley with the goal of accurate stature estimation. Rosing (1988) gives an excellent review of the research on stature estimation employing the skeleton.

Dwight (1894) became interested in the problem of stature reconstruction through his work in personal identification in medico-legal cases, and described two methods he termed the anatomical method and the

mathematical method . The anatomical method invovled placing the skeletal elements in as close to anatomical order as possible, and after accounting for soft tissue, measuring the lengths and calculating the height of the individual. The mathematical method recognizes that certain bones of the skeleton are proportional to the stature. Dwight discusses the works of Topinard, Rollet (1888) and Manouvrier (1893) regarding the mathematical methods available at the time. The methods of the time were found to be lacking, and more studies were conducted. The important aspect of these early works is that researchers recognized the relationship between bone length and stature (Pan, 1924). Pearson (1899) provided formulae for the estimation of statures which were used for several decades.

In the next half century, many studies were conducted to improve these methods of stature reconstruction. It was recognized, as time passed, that these formulae were not applicable for all populations. Racial differences as well as sexual dimorphism were thought to be reflected in heights (Stevenson, 1929). Dupertuis and Hadden (1951) addressed these particular factors. The sample employed for their study was the Todd Collection (see Table 1), which at the time represented a modern or recent living population of whites and blacks of both sexes. All of the major long bone lengths and some of their combinations, such as femur plus tibia or humerus plus radius, were employed for stature

Table 1. Selected samples used in stature research.

Author(s)	Source	N	White		Black		Mexican		Mongoloid
			M	F	M	F	M	F	M
Dupertious & Hadden (1951)	Todd Collection	400	100	100	100	100	-	-	-
Trotter & Gleser (1952)	Military Personnel (WWII)	1,200	1,115	-	85	-	-	-	-
	Terry Collection	855	255	63	360	177	-	-	-
Trotter & Gleser (1958)	Military Personnel (Korean War)	5,517	4,672	-	577	-	112	-	156
Genoves (1968)	Anatomy Cadavers	98	-	-	-	-	69	29	-

regressions. Dupertuis and Hadden (1951) provide regression formulae for each of the bones and combinations of bones for white males, black males, white females, and black females. They compare their results with Pearson's (1899) study of the French sample and as expected indicate that there are differences between the populations. They recommend use of the formulae derived from the appropriate sample when estimating stature.

About this same time, Trotter and Gleser were working on trends in stature among Americans of different races (1951b), age changes in stature (1951a), and stature estimation (1952). Their stature reconstruction formulae are still the most often used for estimation of stature for Americans today. The sample that Trotter and Gleser employed was drawn from American World War II casualties in the Pacific zone and the Terry Collection of whites and blacks of both sexes (1952). The Terry Collection include individuals who lived in the St. Louis, Missouri, area at the time of death and had been collected from 1924 until the middle of the 1950's as dissecting room cadavers. Details of their sample are given in Table 1. This sample was much larger than Dupertuis and Hadden's sample (1951) for all groups except for the white females. The lengths of the long limb bones were measured, and stature regressed on these. The formulae were provided for each of the bones as well as combinations of bones. Other estimation formulae

were provided as well. In 1958, Trotter and Gleser re-evaluated their previous study (1952) while employing more of the American war dead. The later study included new equations for the estimation of stature for American Mongoloid, Mexican, and Puerto Rican males. Based on the differences they found between the two military samples, it has been suggested that the later study be used in the estimation of stature. In 1970, Trotter published this research using these samples again.

Another study conducted on the estimation of stature using long limb bones is that of Genoves (1967) on Mesoamericans. The factor of racial differences or population differences was the impetus for Genoves' work. He calculated stature of a prehispanic population from Mexico using a study based on a British population, and the results were "absurd". The need for formulae for Mexicans was apparent. The sample included 69 males and 29 females from the "morphological categories I (Indigencus) or IM (Indigenous with some mestizo), as confirmed by serological analysis"(Genoves, 1967). The formulae are quite different than those proposed by Trotter and Gleser (1958) for Mongoloid individuals. This difference might result from the small sample size, but it probably reflects the population differences in the two samples.

While these studies and others (see Shao, 1989; Lundy, 1983; Olivier,1963; Fully and Pineau, 1960; Keen, 1953;

Telkka, 1950; Breitinger, 1937)) have employed the intact long limb bones for various adult populations, research has also been conducted on the use of fragmentary long bones as a means for the estimation of stature. Steele and McKern (1969) and Steele (1970) present a method of allowing use of fragmentary long bones in the estimation of maximum long bone length and living stature. One of the difficulties arising from the Steele method is finding the precise location of the specified landmarks.

Simmons et al. (1990) reexamine the feasibility of calculating stature from fragmentary long bones. They use standard, clearly defined landmarks on the femur. The femur was chosen because of the high correlation with stature as well as being commonly recovered. The sample used was the Terry Collection with 200 each of blacks and whites for both sexes. The Simmons et al. study does give an improved method for stature estimation using fragmentary femora. However, they stress that formulae should be developed using modern populations.

Although long limb bones are highly correlated with stature, it is not always possible to utilize long bones either from the lack of availability or even extreme fragmentation. The use of other skeletal elements for stature estimation has also been examined by various researchers. Such elements as the clavicle (Jit and Singh, 1956), the vertebrae (Fully, 1956; Lundy, 1988), metatarsals

(Byers et al., 1989), and metacarpals (Musgrave and Harneja, 1978) have all been employed for the estimation of stature for adults. Some of the research focusing primarily on children and stature estimation include Imrie and Wyburn (1958), Blanco et al. (1974), Himes et al. (1976), Malina and Zavaleta (1980) and Malina et al. (1987).

Some of the problems inherent in stature estimation include the reliability of the living stature, secular trends in stature, and the effects of age on stature. All of these have been considered in the literature. The problem of reliable living statures comes in the form of reported heights versus actual height (Boldsen et al., 1986; Willey and Falsetti, 1987; Himes and Roche, 1982). The Forensic Data Bank housed at the University of Tennessee, Knoxville, has data on over 700 individuals that include skeletal metrics, nonmetrics, and as much personal information as could be obtained on modern forensic cases (Jantz and Moore-Jansen, 1988). The statures of the individuals are also obtained, but often are those from missing persons reports or driver's licenses. Willey and Falsetti (1987) show the height information on driver licenses can be quite inaccurate. It is this unreliability in known statures of modern individuals that limits more recent studies with modern populations.

Secular trend in stature is a topic of great interest and can be problematic too. Cannon (1986), Prince (1989),

and others have examined secular change in heights of American Indian groups. Relethford and Lees (1981) examined Irish secular trends, while Ling and King (1987) evaluated Chinese children and secular trend in stature. Other populations that have been studied with regard to secular trend in stature include the English and Scottish (Chinn et al., 1989), Swedish (Sandberg and Steckel, 1987; Lindgren and Hauspie, 1989), South and Central America (Himes and Mueller, 1977; Pruzack et al., 1988), African (Price et al., 1987),and American (Trotter and Gleser, 1951b). Historical populations have not been neglected either. Genoves (1966), Margo and Steckel (1983), Fogel (1986), and Steckel (1987) have all reported on secular changes in heights of the last century.

Secular changes not only affect statures. Himes (1984) reports that there is a secular change in bone age as seen in radiographs.

Changes due to aging are also important considerations when statures are measured. Height loss from aging has been well documented (Trotter and Gleser, 1951a; Relethford and Lees, 1981; Galloway, 1988; Cline et al., 1989). Because of the height loss during aging, known statures and estimated statures must be adjusted. Trotter and Gleser (1951a) provide information and formulae for the adjustment of stature loss in using the Terry Collection. However, it has been documented that the individuals from the cohort of the

Terry Collection, born between the latter part of the 19th Century and the early part of the 20th Century, are not of comparable heights (Fogel, 1986). Secular changes also affect the amount of height loss due to aging. Galloway (1988) reports data on modern stature loss in living people and suggests that secular changes have stablized. The effect of aging is much more rapid and begins later than suggested by Trotter and Gleser (1951a) as seen in the mean annual loss of .16 centimeter (cm) beginning at age 45 years in Galloway's research, and the mean annual loss of .06 cm beginning at age 30 (arbitrary age) in Trotter and Gleser's research.

Another study of height loss with age is by Cline et al. (1989). Their sample included living white individuals that were measured twice over a period of several years. They found that on the average, height loss begins about age 40 for both males and females. However, the rates of decline in stature were sufficiently different to warrant two different formulae. While all of these age changes are shown, again the correct formulae for correcting to maximum stature depend on the population in use including the age cohorts. Behrents and Harris (1987) report that normal length changes (increasing and decreasing) occur in hand bones during adulthood. These studies indicate that differences do occur among populations and must be taken into consideration when estimating stature.

CHAPTER III

OBJECTIVES

The objectives of this research are threefold including:

1. Estimate the strength of the relationship between metacarpal length and stature.
2. Estimate regression equations allowing stature estimation from metacarpal length.
3. Test these equations on a modern sample and adjust them if necessary.

The null hypothesis for this research is that metacarpal length has no correlation with stature. The test hypothesis is that metacarpal length is correlated with stature, and that adult stature can be predicted based on the lengths of one or more metacarpal lengths.

CHAPTER IV

MATERIALS AND METHODS

A. TERRY COLLECTION SAMPLE

A total of 212 individuals from the Terry Collection, housed at the Smithsonian Institution in Washington, D.C., were included in the sample of dry bone data (Table 2). The Terry Anatomical Collection consists of 1636 cadavers that were collected and macerated in the early 20th century in St. Louis, Missouri (Terry, 1940).

All 10 metacarpals were measured for 53 black males, 56 white males, 55 black females, and 48 white females. The majority of these individuals were chosen based on use in a previous stature study (Simmons et al., 1990). Other criteria for inclusion in the sample were known age, race, sex, and stature.

Demographic data and stature were recorded. The stature, stated in centimeters, had been measured by hanging the cadaver in a vertical position to simulate standing height (Terry, 1940; Trotter and Gleser, 1952). A small percentage of the cadavers in the Terry Collection were not positioned with the soles of the feet flat as seen in some

Table 2. Composition of the Terry Collection sample (N=212).

Race	Sex	N	Mean Age	Std Dev
White	Male	56	57.82	14.4324
White	Female	48	64.33	15.9071
Black	Male	53	45.77	16.3244
Black	Female	55	42.04	17.7743

of the photographs (Trotter and Gleser, 1952). These individuals were not included in the sample.

The two measurements employed in this study include maximum metacarpal length and midline length (see Roche and Hermann, 1970). The maximum metacarpal length is defined as the length from the most proximal projection to the most projecting portion of the distal articular surface, while the midline length is defined as the length from the midline of the proximal articular surface to the midline of the distal articular surface (Fig. 1). A Helios dial caliper was used to take the measurements which were recorded to the nearest tenth of a millimeter. These data were recorded on specially designed data forms (Appendix 1.).

The data were entered for statistical analysis using the SAS system (Schlotzhauer and Littell, 1987). The first step was to adjust stature for cadaveral stature by subtracting two centimeters from each individual (Genoves, 1967; Byers et al., 1989). Next, Pearson Correlation Coefficients were calculated to determine whether age correlated with stature. Initially Trotter and Gleser's (1951a) age adjustment formula was applied to this sample of the Terry Collection. However, a residual negative correlation (a=.05) between stature and age suggested that a secular trend effect was present in this sample of the Terry Collection that was different than that found in Trotter and Gleser's sample.

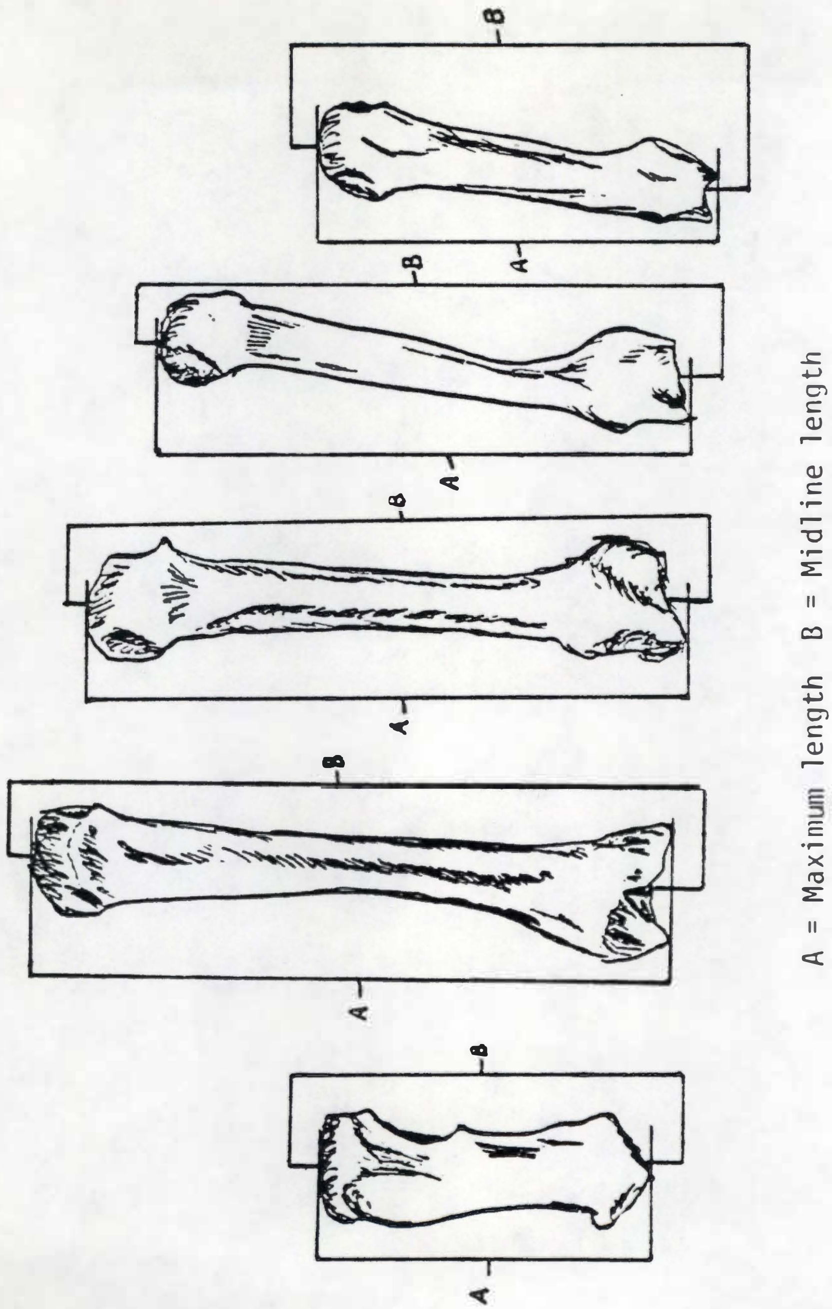

Figure 1. Metacarpals illustrating the two measurements.

Similar methods to those used by Trotter and Gleser (1951a) were followed in determining the aging changes using the maximum length of the femur. The intercorrelations among age, stature, and femur length and the slope of the line of regression between stature and age were obtained. The age of 30 as used by Trotter and Gleser was replaced by age 45. Galloway (1988) and Cline et al. (1989) report that stature loss begins around this age. The model used to determine maximum height is as follows:

$$Height = a + b1(femur) + b2(age)$$

B2 is the partial regression coefficient that describes height loss with age after controlling for femur so that the final equation is Maximum Height = Height - b2(age-45). Using these data, maximum height was obtained for use in further analysis.

The general linear model procedure was applied for each group (black males etc.) using each bone and each measurment to estimate the strength of the relationship between each measurement and stature. Variations in slopes of the equations for each group was examined (a=.05). If no significant differences in slope occur, then solutions to these equations can be estimated using the same intercept for each group. Stepwise regression was also performed to determine whether multiple bones improved the relationship between stature and bone lengths. All analyses were conducted on both left and right sides separately.

B. MODERN SAMPLE

A sample of modern Americans was employed to test for possible changes in stature or bone length due to secular trend (Table 3). This sample included both left and right hand radiographs of 30 black and 25 white males, examined at the Regional Forensic Center in Memphis, Tennessee, between May and November, 1989. Age, race, sex, and stature were recorded for each individual, although age is unavailable for 3 individuals. Otherwise the sample is complete. The stature was measured using an anthropometer from heel to crown while the body was in a supine position, and recorded in centimeters to the nearest half centimeter. These statures were then adjusted for cadaveral statures by subtracting 2 cm.

The radiographs were made with the hand secured with a plexiglass sheet clamp held in place with four-inch screws and wingnuts. The hand was positioned palm up so that the dorsal surface was closer to the film to minimize distortion. A scale was taped to the film cassette. The machine employed for the radiography was a Bennett, Machlett Collimaster M, Type 42 (for further specifications on the machine see Appendix 2). The settings for the radiographs

Table 3. Composition of the modern sample (N=55).

Race	Sex	N	Mean Age	Std Dev
White	Male	25	46.29	21.5113
Black	Male	30	42.21	14.9427

were as follows: KV-60, MA-100, SEC-1/120. The cone of the machine was 76 cm from the film.

The metacarpal measurements taken on the radiographs include the midline length as defined above as well as the maximum length of the first metacarpal. Overlapping images on the radiographs precluded maximum length measurements on the other metacarpals. A Helios dial caliper was used to measure to the nearest tenth of a millimeter (mm). These data were recorded on specially designed recording forms (Appendix 3).

The scale used on the radiographs was measured to test for paralax. Twenty diameters of the standard on radiographs were measured to the nearest thousandth of a millimeter, and a mean was determined. Two diameters were measured on the actual standard to the same accuracy and averaged. The actual standard mean was then subtracted from the radiographic standard mean to determine the adjustment required for each of the radiographic images and measurements. The adjustment was then subtracted from each of the bone measurements.

A negative correlation between age and stature necessitates the adjustment of stature for age. Galloway's (1988) formula, stature = stature + .16(Age-45), was employed for this adjustment. This particular adjustment formula was chosen for the application to the modern sample.

Using these data, summary statistics and Pearson's correlation coefficients were obtained for all the variables. All analyses were conducted on both left and right sides separately.

C. COMPARISON OF TERRY COLLECTION AND MODERN SAMPLES

Comparison of the Terry Collection with modern samples included tests for equality of slopes and for equality of adjusted means between these groups for white and black males. In order to employ the modern sample to adjust the regression equations based on the Terry Collection sample for use on modern American populations, these tests of equality were necessary to establish how the two groups differ. Analysis of covariance (Tatsuoka, 1971) was utilized to test for equality of slopes and for equality of adjusted means.

D. TEST SAMPLE

The test sample consisted of 10 males (8 white, 2 black) of known sex, race, age (except one), and stature from the donated and forensic skeletal collections in the Department of Anthropology, University of Tennessee, Knoxville. Only males are employed because insufficient data on modern

females precluded adjusted formulae. Statures were cadaver statures with only one exception. These cadaver statures were adjusted by subtracting 2 centimeters, and all statures for individuals over 45 years were adjusted using Galloway's (1988) formula to obtain maximum heights.

Measurements taken include the measurements seen in Figure 1 on the metacarpals available. These data were applied to the new formulae based on the combined Terry and modern samples to test the reliability of these formulae.

CHAPTER V

RESULTS

A. TERRY COLLECTION

The aging coefficients found by least squares analysis are given in Table 4 and were used to adjust the recorded stature to the maximum stature for individuals 45 years or older. The maximum statures are used for the remaining analysis. Summary statistics are given by groups in Tables 5-12 (see Appendix 4 for abbreviated variable names).

The strengths of the relationships between metacarpal lengths and stature are reflected in the correlation coefficients for each of the ten measurements for both left and right sides, and these are given in Tables 13 and 14 (see Appendix 5 for Pearson Correlation Coefficients). Tests for slope differences were not significant. This enabled the same intercept to be applied to each group in the equations for stature estimations. These equations are given in Tables 15 and 16. Dummy variables are employed in these regression equations , and these variables are equal to 0 except for the group that is being tested. The equation is as follows:

$$Stat = intercept + b1*(variable) + b*(group)$$

The stepwise analysis revealed that nothing significant

Table 4. Age adjustment formulae for Terry Collection.

Race	Sex	Formula
White	Male	Max. Stature = Stat + .09880(Age-45)
White	Female	Max. Stature = Stat + .18294(Age-45)
Black	Male	Max. Stature = Stat + .04794(Age-45)
Black	Female	Max. Stature = Stat + .06065(Age-45)

Results in centimeters.

Table 5. Summary statistics for white males.
Left side. (N=56)

Variable	Mean	Std Dev	Variance	Minimum	Maximum
Age	57.8214	14.4324	208.2948	20.00	84.00
Stature	169.1292	7.4785	55.9281	151.30	186.00
M1XL	46.7768	2.8863	8.3309	41.30	51.90
M1ML	46.1232	2.9829	8.8978	39.50	51.10
M2XL	69.8821	4.2279	17.8753	60.40	79.00
M2ML	66.4679	4.0795	16.6422	56.90	75.00
M3XL	68.7679	3.8774	15.0346	60.30	76.40
M3ML	64.8911	3.7467	14.0376	57.40	72.10
M4XL	58.6411	3.7451	14.0257	51.60	65.30
M4ML	58.0857	3.7325	13.9318	50.90	64.40
M5XL	55.0000	3.2871	10.8047	48.50	60.30
M5ML	53.4554	3.3672	11.3378	45.60	59.00

Table 6. Summary statistics for white females.
Left side. (N=48)

Variable	Mean	Std Dev	Variance	Minimum	Maximum
Age	64.3333	15.9071	253.0354	27.00	88.00
Stature	161.5367	7.6443	58.4355	139.46	177.46
M1XL	43.5208	2.9766	8.8600	37.20	50.90
M1ML	43.0104	2.9597	8.7597	37.20	50.90
M2XL	65.1542	4.1318	17.0719	56.40	73.70
M2ML	62.2792	4.1137	16.9225	54.10	72.10
M3XL	63.9958	4.4529	19.8281	55.40	73.40
M3ML	60.6500	4.2017	17.6540	51.50	69.60
M4XL	54.8125	3.8671	14.9547	45.60	62.20
M4ML	54.1833	3.7793	14.2831	45.30	61.90
M5XL	50.9063	3.4183	11.6849	44.20	57.30
M5ML	49.7313	3.3621	11.3039	43.60	56.60

Table 7. Summary statistics for black males.
Left side. (N=53)

Variable	Mean	Std Dev	Variance	Minimum	Maximum
Age	45.7736	16.3244	266.4862	17.00	76.00
Stature	171.3595	7.4087	54.8887	154.72	186.20
M1XL	49.8038	2.9030	8.4277	43.00	56.70
M1ML	49.3038	2.8460	8.0996	42.50	56.10
M2XL	74.1679	4.2627	18.1707	65.50	83.00
M2ML	71.1472	4.0780	16.6298	63.30	80.20
M3XL	73.7924	4.5928	21.0938	64.00	83.10
M3ML	70.1642	4.2125	17.7454	61.60	79.40
M4XL	62.8566	3.9660	15.7294	54.30	71.00
M4ML	62.3018	4.0142	16.1140	52.50	71.00
M5XL	58.8434	3.5791	12.8102	51.10	67.30
M5ML	57.3434	3.5687	12.7356	49.30	65.80

Table 8. Summary statistics for black females. Left side. (N=55)

Variable	Mean	Std Dev	Variance	Minimum	Maximum
Age	42.0364	17.7743	315.9246	16.00	101.00
Stature	159.3646	6.9604	48.4468	144.00	175.00
M1XL	44.7634	2.6460	7.0012	40.00	52.10
M1ML	44.2182	2.6567	7.0582	39.80	51.70
M2XL	68.3255	4.1809	17.4797	60.90	82.70
M2ML	65.5782	3.9819	15.8554	58.70	79.00
M3XL	67.7018	3.9298	15.4435	60.50	81.00
M3ML	64.3836	4.0103	16.0829	57.20	77.80
M4XL	57.5910	3.6533	13.3464	51.90	68.80
M4ML	57.0782	3.6983	13.6777	51.50	68.70
M5XL	53.0291	3.2326	10.4499	46.90	62.50
M5ML	52.0345	3.1730	10.0682	46.40	61.70

Table 9. Summary statistics for white males.
Right side. (N=56)

Variable	Mean	Std Dev	Variance	Minimum	Maximum
Age	57.8214	14.4324	208.2948	20.00	84.00
Stature	169.1292	7.4785	55.9281	151.30	186.00
M1XL	47.3661	3.1474	9.9063	41.00	53.80
M1ML	46.6214	3.0582	9.3526	39.80	52.20
M2XL	69.7321	4.2108	17.7309	61.10	77.90
M2ML	66.3304	4.0197	16.1578	57.40	73.90
M3XL	68.6321	3.9993	15.9946	60.10	77.80
M3ML	65.0250	3.6829	13.5637	56.40	73.70
M4XL	58.4857	3.7563	14.1100	50.70	65.00
M4ML	57.8893	3.6095	13.0286	50.50	64.30
M5XL	54.6304	3.0954	9.5818	48.90	59.80
M5ML	53.0089	3.1304	9.7994	47.20	58.40

Table 10. Summary statistics for white females.
Right side. (N=48)

Variable	Mean	Std Dev	Variance	Minimum	Maximum
Age	64.3333	15.9071	253.0355	27.00	88.00
Stature	161.5367	7.6443	58.4355	139.46	177.48
M1XL	43.7729	2.9624	8.7756	37.00	50.40
M1ML	43.1000	2.9152	8.4983	36.60	49.90
M2XL	65.6333	4.5058	20.3023	56.60	76.00
M2ML	62.6771	4.4853	20.1175	53.40	73.00
M3XL	64.2500	4.3687	19.0860	55.00	73.30
M3ML	61.0771	4.2955	18.4516	51.30	70.40
M4XL	55.1938	4.0581	16.4678	45.50	62.70
M4ML	54.6208	3.9614	15.6923	45.30	62.30
M5XL	51.1813	3.4418	11.8458	44.00	58.10
M5ML	49.9479	3.4145	11.6591	42.70	56.40

Table 11. Summary statistics for black males.
Right side. (N=53)

Variable	Mean	Std Dev	Variance	Minimum	Maximum
Age	45.7736	16.3244	266.4862	17.00	76.00
Stature	171.3595	7.4087	54.8887	154.72	186.20
M1XL	50.2774	3.1468	9.9026	43.10	57.90
M1ML	49.5415	3.1078	9.6582	42.20	56.70
M2XL	74.2698	4.1748	17.4287	65.80	83.10
M2ML	71.1981	4.0150	16.1206	62.90	79.60
M3XL	73.7208	4.4540	19.8382	63.90	83.50
M3ML	70.1943	4.1537	17.2529	61.50	79.50
M4XL	62.7547	3.6805	13.5464	55.20	70.00
M4ML	62.2038	3.6579	13.3804	54.10	69.80
M5XL	58.7340	3.5561	12.6461	50.80	66.90
M5ML	57.2189	3.5440	12.5600	49.20	65.00

Table 12. Summary statistics for black females. Right side. (N=55)

Variable	Mean	Std Dev	Variance	Minimum	Maximum
Age	42.0364	17.7743	315.9246	16.00	101.00
Stature	159.3646	6.9604	48.4468	144.00	175.00
M1XL	45.1255	2.6668	7.1116	39.00	51.10
M1ML	44.5309	2.6999	7.2996	38.70	50.90
M2XL	68.6091	4.0758	16.6120	60.60	82.70
M2ML	66.0418	4.2469	18.0358	58.50	79.00
M3XL	67.8764	3.9962	15.9696	59.60	79.90
M3ML	64.5709	3.7649	14.1743	57.10	76.70
M4XL	57.5200	3.6499	13.3216	49.10	67.70
M4ML	56.9472	3.6475	13.3044	48.90	67.50
M5XL	53.3655	3.1153	9.7053	47.10	62.50
M5ML	52.2982	3.0966	9.5887	46.50	61.80

Table 13. Correlation coefficients for stature. Left side. (All significant at p<.0001)

Variable	White Male	White Female	Black Male	Black Female
M1XL	.658	.677	.645	.646
M1ML	.659	.667	.627	.648
M2XL	.801	.787	.672	.611
M2ML	.809	.788	.676	.613
M3XL	.805	.694	.616	.659
M3ML	.825	.746	.613	.671
M4XL	.828	.701	.582	.669
M4ML	.816	.711	.599	.677
M5XL	.747	.667	.606	.615
M5ML	.780	.685	.604	.611

Table 14. Correlation coefficients for stature. Right side. (All significant at p<.0001)

Variable	White Male	White Female	Black Male	Black Female
M1XL	.618	.701	.668	.660
M2ML	.641	.704	.653	.668
M2XL	.791	.779	.646	.650
M2ML	.790	.779	.655	.641
M3XL	.756	.692	.565	.676
M3ML	.785	.710	.572	.698
M4XL	.816	.697	.608	.609
M4ML	.811	.724	.615	.614
M5XL	.656	.631	.616	.619
M5ML	.704	.640	.591	.634

Table 15. Regression equations for the Terry Collection. Left side.

Variable	b1	White Male b2	White Female b3	Black Male b4	Black Female b5	a	S.E.
M1XL	1.696	2.07	0.00	-0.84	-4.28	87.69	5.57
M1ML	1.674	2.38	0.00	-0.71	-4.19	89.52	5.61
M2XL	1.258	1.64	0.00	-1.52	-6.16	79.55	5.14
M2ML	1.311	2.10	0.00	-1.81	-6.50	79.86	5.10
M3XL	1.208	1.83	0.00	-2.01	-6.65	84.21	5.34
M3ML	1.298	2.09	0.00	-2.53	-7.02	82.81	5.19
M4XL	1.346	2.44	0.00	-1.01	-5.91	87.74	5.31
M4ML	1.355	2.30	0.00	-1.18	-6.10	88.11	5.27
M5XL	1.437	1.71	0.00	-1.58	-5.22	88.38	5.56
M5ML	1.468	2.12	0.00	-1.35	-5.55	88.52	5.47

Table 16. Regression equations for the Terry Collection. Right side.

Variable	b1	White Male b2	White Female b3	Black Male b4	Black Female b5	a	S.E.
M1XL	1.626	1.75	0.00	-0.75	-4.37	90.38	5.55
M1ML	1.659	1.75	0.00	-0.87	-4.55	90.02	5.52
M2XL	1.250	2.47	0.00	-0.97	-5.89	79.50	5.14
M2ML	1.261	2.99	0.00	-0.92	-6.41	82.52	5.15
M3XL	1.176	2.44	0.00	-1.31	-6.44	85.99	5.48
M3ML	1.279	2.54	0.00	-1.83	-6.64	83.44	5.36
M4XL	1.336	3.19	0.00	-0.28	-5.28	87.77	5.38
M4ML	1.375	3.10	0.00	-0.60	-5.37	86.44	5.33
M5XL	1.406	2.74	0.00	-0.80	-5.24	89.57	5.74
M5ML	1.433	3.21	0.00	-0.60	-5.54	89.95	5.67

is gained by the addition of more than one variable in a multiple regression determining the relationship between metacarpal lengths and stature.

B. MODERN SAMPLE

The correction for parallax on the radiographs was determined to be .24 millimeter which was subtracted from the relevant data prior to further analysis. Negative correlations between stature and age require correction for age to be calculated. The age corrected statures are listed as the variable ASTAT. The summary statistics are given in Tables 17-20.

The strengths of the relationships between metacarpal lengths and stature are reflected in the correlation coefficients for each of the six measurements for both left and right sides as seen in Table 21. The insignificant correlation coefficients for the white sample probably result from the small sample size (N=25).

C. COMPARISON OF TERRY COLLECTION AND MODERN SAMPLES

Analysis of covariance tests for equality of slopes and of adjusted means between the Terry Collection and the modern samples are given in Tables 22 and 23. These tests

Table 17. Summary statistics for modern white males. Left side.

Variable	N	Mean	Std Dev	Variance	Minimum	Maximum
Age	24	46.2917	21.5113	462.7373	18.00	84.00
Stature	25	171.7600	6.6384	44.0683	153.70	183.00
M1XL	25	47.7880	2.5344	6.4229	41.16	51.16
M1ML	25	47.3760	2.6056	6.7889	39.76	50.96
M2ML	24	70.1767	2.7889	7.7780	64.86	75.06
M3ML	24	68.0558	2.6648	7.1013	62.46	72.76
M4ML	24	61.5475	3.2170	10.3490	56.06	69.26
M5ML	25	56.2600	2.6172	6.8500	50.86	60.36
ASTAT	25	173.3088	6.3332	40.1104	157.38	188.24

Table 18. Summary statistics for modern black males. Left side.

Variable	N	Mean	Std Dev	Variance	Minimum	Maximum
Age	28	42.2143	14.9427	223.2857	20.00	71.00
Stature	30	171.6333	6.6733	44.5333	160.00	185.00
M1XL	30	50.2900	3.6097	13.0298	43.16	61.76
M1ML	30	49.2633	3.7229	13.8596	41.66	61.06
M2ML	30	72.5533	4.1037	16.8406	63.06	80.06
M3ML	30	71.0233	4.8880	23.8927	56.86	81.86
M4ML	30	63.5967	3.9584	15.6686	55.16	73.36
M5ML	30	58.7300	4.1680	17.3718	51.66	70.26
ASTAT	30	172.4547	6.5728	43.2017	160.00	185.00

Table 19. Summary statistics for modern white males. Right side.

Variable	N	Mean	Std Dev	Variance	Minimum	Maximum
Age	24	46.2917	21.5113	462.7373	18.00	84.00
Stature	25	171.7600	6.6384	44.0683	153.70	183.00
M1XL	25	48.2600	2.3567	5.5542	41.46	51.86
M1ML	25	47.8560	2.5254	6.3779	39.76	51.56
M2ML	25	70.1520	2.3051	5.3133	64.46	75.16
M3ML	25	67.7360	2.2393	5.0144	62.96	71.46
M4ML	25	60.9480	2.2775	5.1869	56.96	65.46
M5ML	25	56.0280	2.5421	6.4623	51.66	60.16
ASTAT	25	173.3088	6.3333	40.1104	157.38	188.24

Table 20. Summary statistics for modern black males. Right side.

Variable	N	Mean	Std Dev	Variance	Minimum	Maximum
Age	28	42.2143	14.9427	223.2857	20.00	71.00
Stature	30	171.6333	6.6733	44.5333	160.00	185.00
M1XL	29	50.9531	3.7730	14.2357	43.26	63.26
M1ML	29	49.6359	4.5921	21.0876	37.26	61.36
M2ML	30	72.6533	4.2099	17.7234	63.46	80.76
M3ML	30	71.5933	4.2077	17.7044	62.36	82.06
M4ML	30	64.0700	4.0447	16.3596	56.36	75.86
M5ML	30	58.5167	4.0794	16.6419	48.56	71.56
ASTAT	30	172.4547	6.5728	43.2017	160.00	185.00

Table 21. Correlation coefficients for stature on modern male sample.

Variable	White L	White R	Black L	Black R
M1XL	.432	.134*	.463	.486
M1ML	.417	.086*	.459	.543
M2ML	.545	.198*	.626	.685
M3ML	.408	.372*	.686	.683
M4ML	.258*	.410	.457	.634
M5ML	.478	.506	.427	.481

* p>.05

Table 22. Tests for equality of slopes and adjusted means. Left side.

Variable	Whites				Blacks			
	Slope		Mean		Slope		Mean	
	F	p	F	p	F	p	F	p
M1XL	1.3632	>.05	3.4749	~.05	3.8989	<.05	0.1189	>.05
M1ML	1.5141	>.05	2.6628	>.05	4.0280	<.05	0.0008	>.05
M2ML	0.4027*	>.05	0.4002*	>.05	0.5400	>.05	0.1777	>.05
M3ML	2.6908*	>.05	0.0044*	>.05	0.9006	>.05	0.0018	>.05
M4ML	9.2697*	<.05	0.0012*	>.05	0.9892	>.05	0.0018	>.05
M5ML	1.7027	>.05	0.0051	>.05	2.7813	>.05	0.0042	>.05
	DF = 1 and 77 *DF = 1 and 76		DF = 1 and 78 *DF = 1 and 77		DF = 1 and 79		DF = 1 and 80	

Table 23. Tests for equality of slopes and adjusted means. Right side.

Variable	Whites				Blacks			
	Slope		Mean		Slope		Mean	
	F	p	F	p	F	p	F	p
M1XL	3.4650	<.05	4.0518	<.05	3.5178*	~.05	0.0050*	>.05
M1ML	5.0103	<.05	3.0441	>.05	4.9502*	<.05	0.6154*	>.05
M2ML	3.4058	~.05	0.4649	>.05	0.2092	>.05	0.2293	>.05
M3ML	1.3099	>.05	0.0006	>.05	0.0022	>.05	0.0757	>.05
M4ML	1.2351	>.05	0.9174	>.05	0.4047	>.05	0.6586	>.05
M5ML	0.7018	>.05	0.1656	>.05	1.6532	>.05	0.0038	>.05
	DF = 1 and 77		DF = 1 and 78		DF = 1 and 79		DF = 1 and 80	
					*DF = 1 and 78		*DF = 1 and 79	

indicate for the white males that only M1XL slopes and means are not equal ($p<.05$) and for the right side M1XL, M1ML, and M2ML slopes and means are not equal. All of the remaining variables tested for the left and right sides show insignificant differences or essentially equal slopes and adjusted means (see Table 22). The variable yielding the smallest standard error of estimate is left M2ML with 4.68, and the largest standard error is 5.78 for left M1ML. Plots of the two samples for left M2ML illustrate the equality of slopes in Figure 2, and the inequality of slopes for right M1ML are illustrated in Figure 3. These equal slopes and means allow for the two samples to be combined, thus increasing sample size from 56 to 81, for all of the remaining variables in formulating regression equations for stature estimation for white males. These equations are given in Table 24.

The tests of equality for slopes and adjusted means for black males yielded slightly different results. For the left and right sides, both M1XL and M1ML were significantly different. The variables that tested equal or insignificantly different for slopes and adjusted means allow the two samples to be combined for each variable thus increasing the sample size from 53 to 83. The adjusted regression equations for black males stature estimation are given in Table 25. The equation with the lowest standard error of estimation is the right M2ML at 5.30, and the

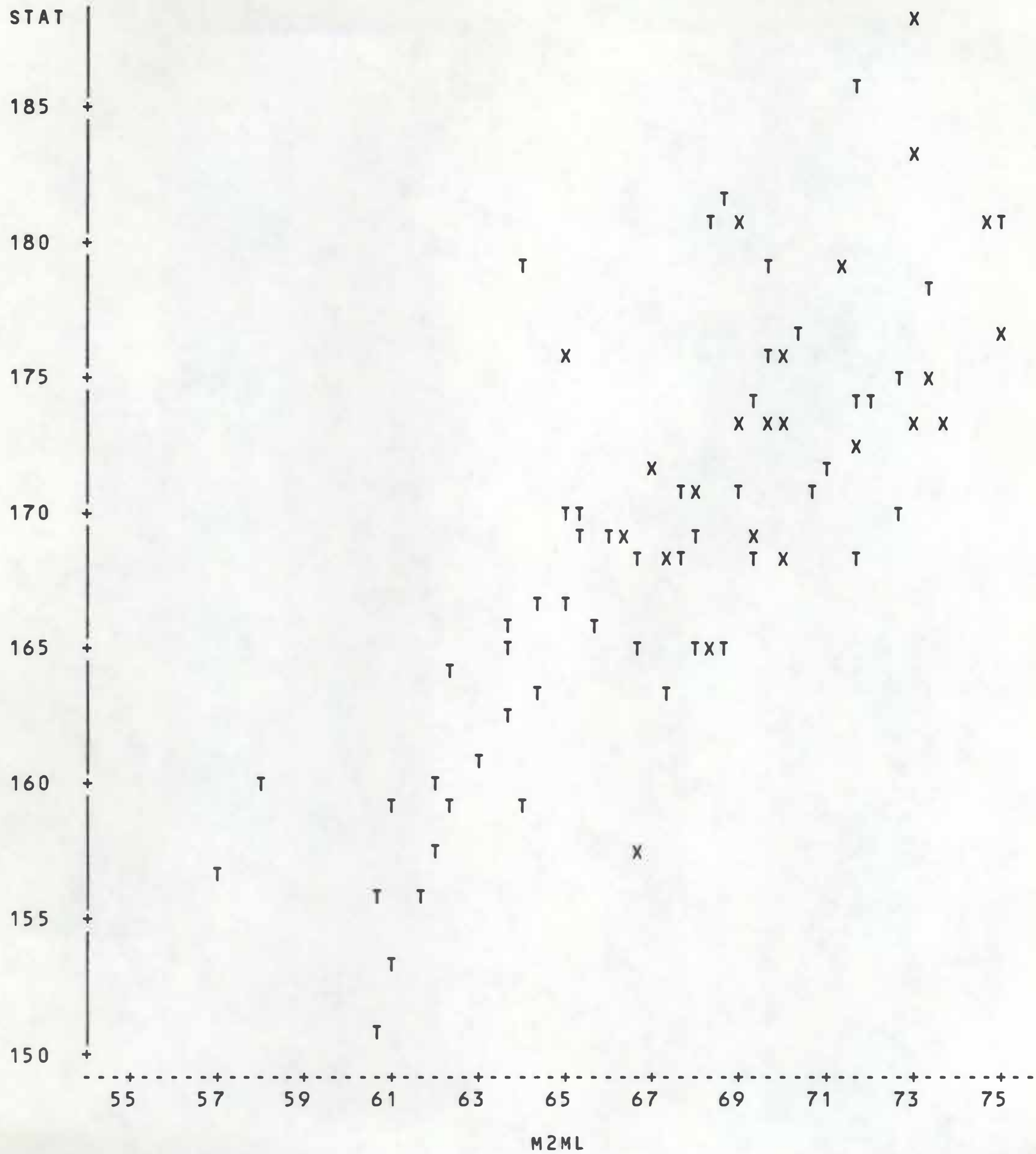

Figure 2. Equality of slopes for white males left M2ML.
'T' = Terry Collection 'X' = Modern Sample

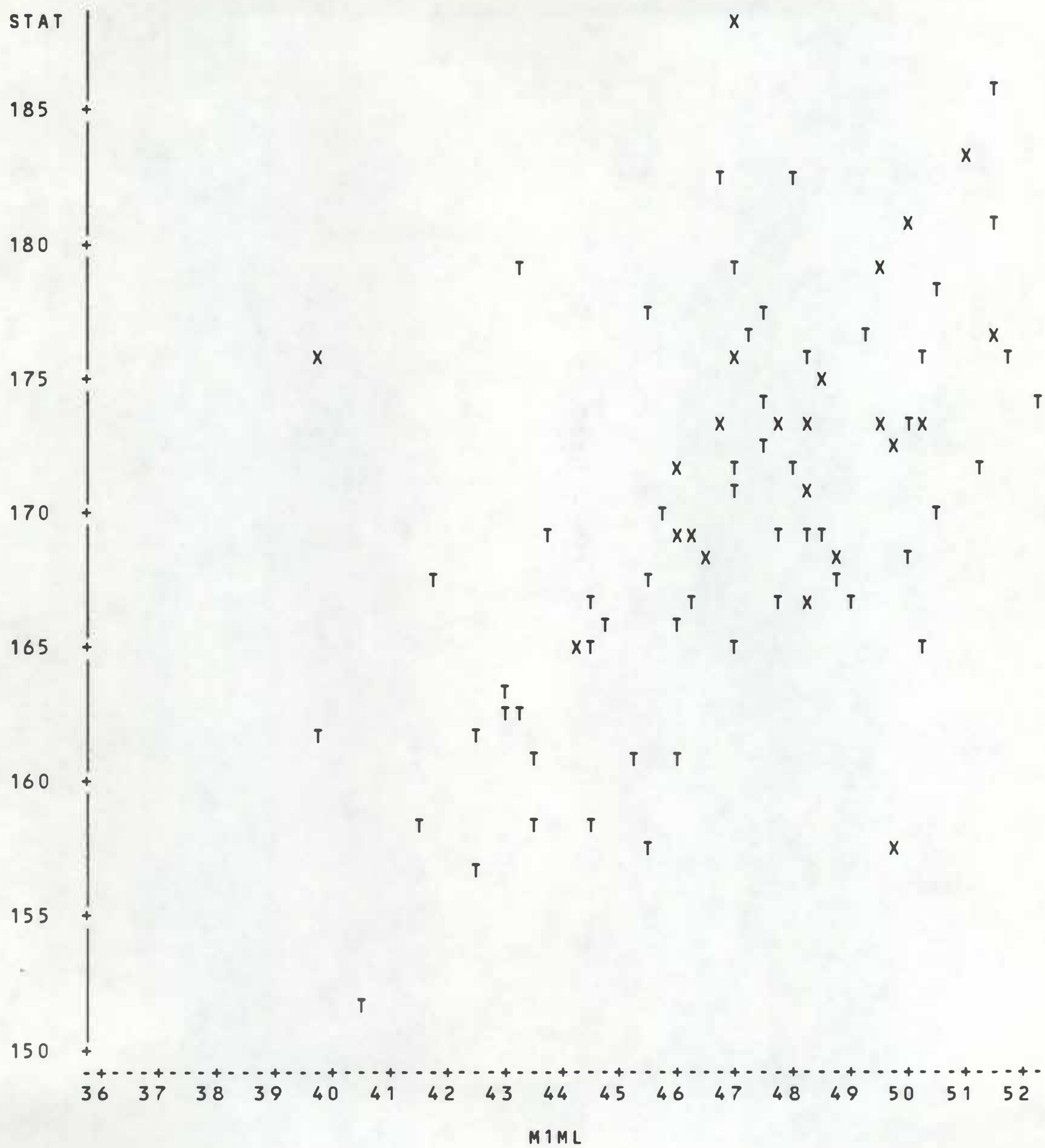

Figure 3. Inequality of slopes for white males right M1ML.

'T' = Terry Collection 'X' = Modern Sample

Table 24. Regression equations for stature estimation of white males.

Left
$1.57\ M1ML + 97.57 \pm 5.78$
$1.40\ M2ML + 75.64 \pm 4.68$
$1.51\ M3ML + 70.83 \pm 4.79$
$1.51\ M5ML + 83.86 \pm 4.99$
Right
$1.52\ M3ML + 70.57 \pm 5.15$
$1.53\ M4ML + 80.37 \pm 4.97$
$1.55\ M5ML + 86.80 \pm 5.44$

Bone length in millimeters.
Stature in centimeters.

Table 25. Regression equations for stature estimations of black males.

Left
1.14 M2ML + 90.32 ± 5.33
1.07 M3ML + 96.43 ± 5.37
0.98 M4ML + 110.27 ± 5.91
1.00 M5ML + 113.86 ± 5.97
Right
1.14 M2ML + 89.70 ± 5.30
1.03 M3ML + 98.92 ± 5.62
1.13 M4ML + 100.87 ± 5.59
1.03 M5ML + 112.09 ± 5.93

Bone length in millimeters.
Stature in centimeters.

highest standard error is 5.93 for right M5ML. A plot of the two samples illustrating equality of slopes for right M3ML are given in Figure 4, while a plot illustrating the unequal slopes for left M1XL are given in Figure 5.

A comparison of the two groups', whites and blacks, regression equations reveals that while blacks have more variables with essentially equal slopes and adjusted means, the standard errors of estimate are larger. The whites have only seven variables that allow for combination of samples for stature estimation, but the standard errors of estimate are smaller.

A comparison of the means for the two samples (Tables 26 and 27) indicates that stature for white males increases over time by 4.2 centimeters, while the increase in stature for black males is only 1.1 centimeter. Upon examination, the variables that had significantly different slopes and/or adjusted means have very similar means. One variable for black males, left M1ML, shows a secular decrease, and yet it has essentially equal slopes for the two samples. Overall, the variables that have the smaller standard error of estimate in the stature equations also have a greater increase in the means over time.

D. TEST SAMPLE

The estimated statures resulting from the new formulae

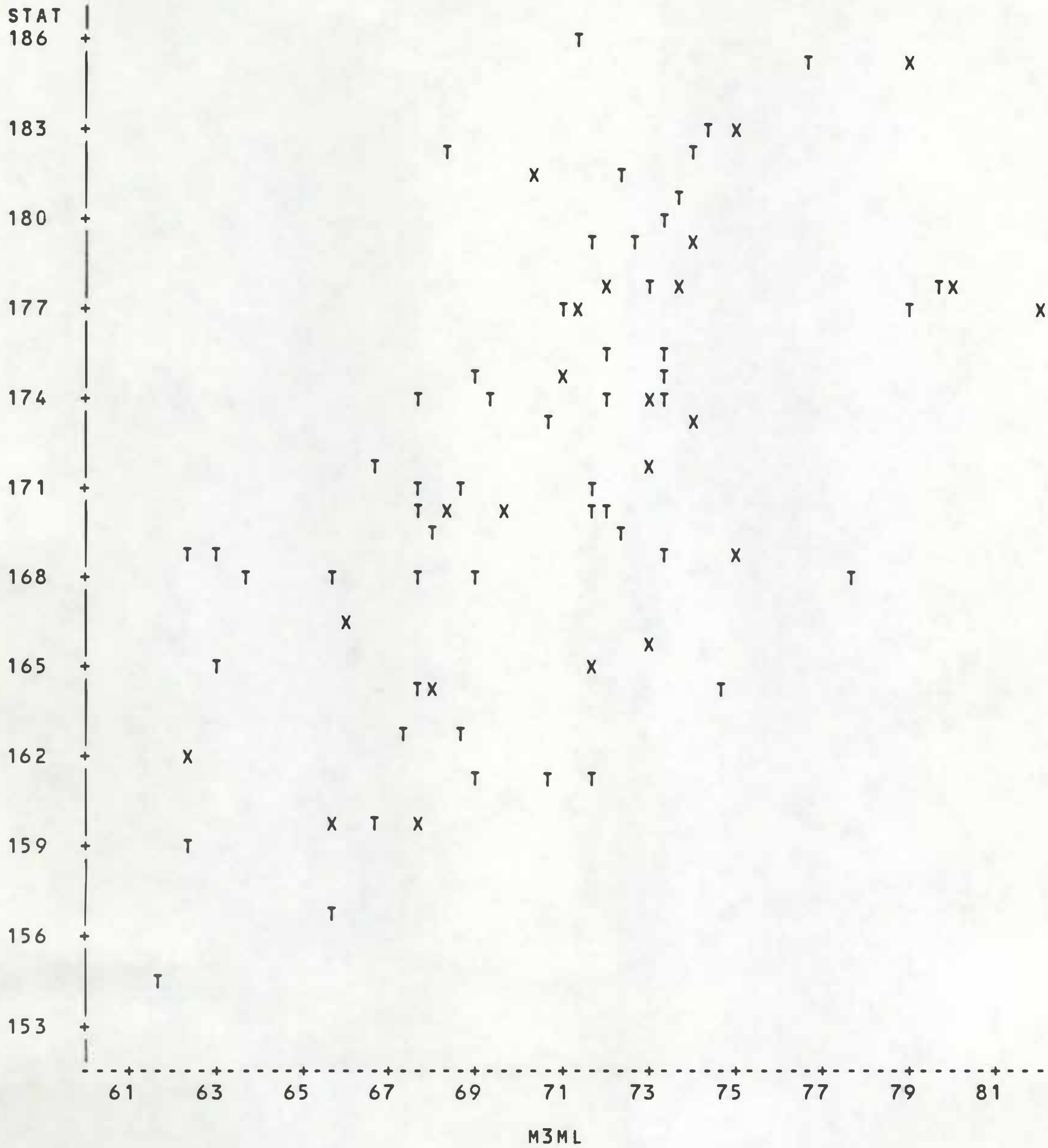

Figure 4. Equality of slopes for black males right M3ML.

'T' = Terry Collection 'X' = Modern Sample

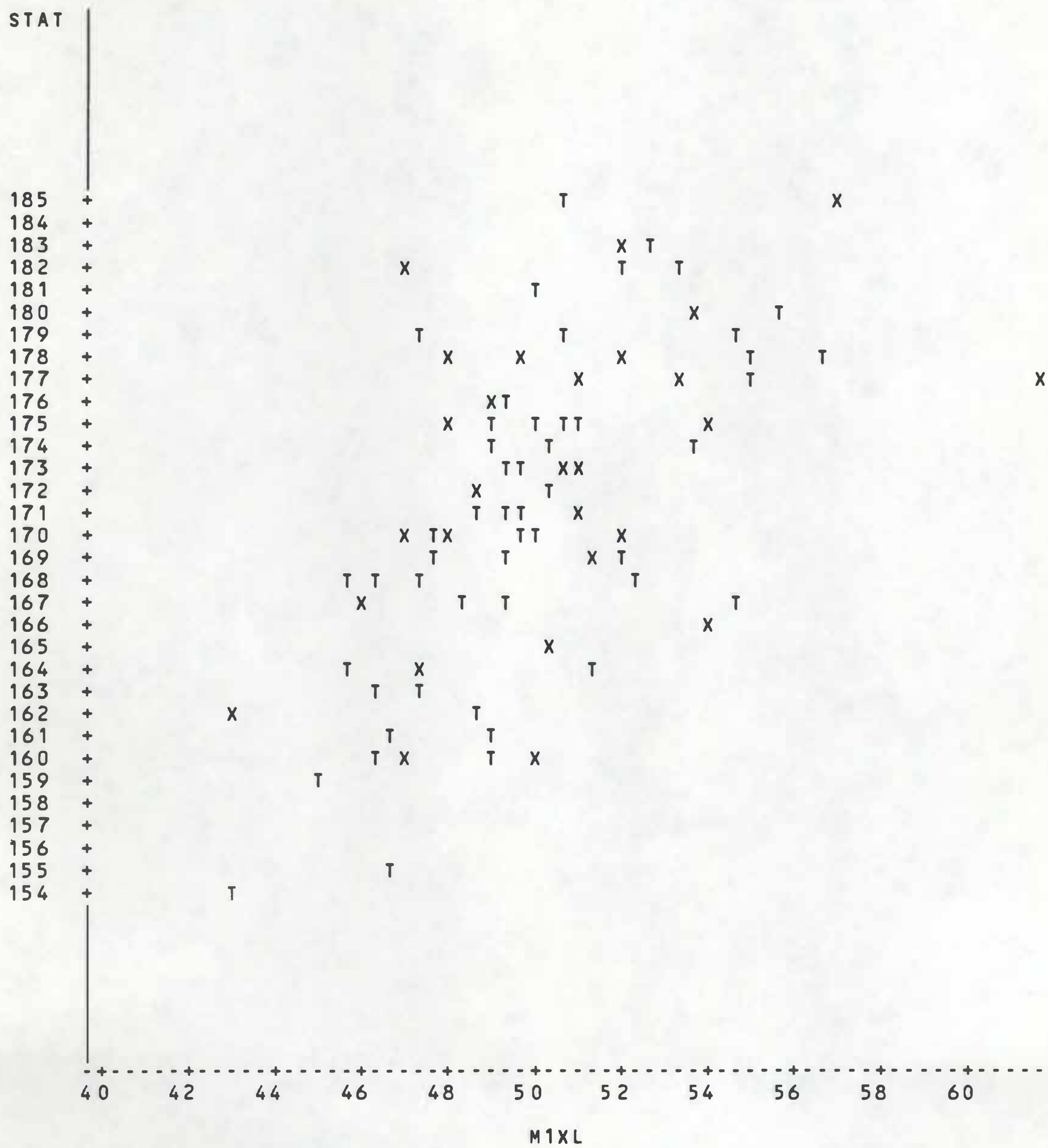

Figure 5. Inequality of slopes for black males left M1XL.

'T' = Terry Collection 'X' = Modern Sample

Table 26. Comparison of means for white males between Terry Collection and modern samples.

Variable	Left Terry (N=56)	Left Modern (N=25)	Right Terry (N=56)	Right Modern (N=25)
Age	57.82	46.29*	57.82	46.29*
Stature (ASTAT)	169.129	173.309	169.129	173.309
M1XL	46.777	47.788	47.366	48.260
M1ML	46.123	47.376	46.621	47.856
M2ML	66.468	70.177*	66.330	70.152
M3ML	64.891	68.056*	65.025	67.736
M4ML	58.086	61.548*	57.889	60.948
M5ML	53.455	56.260	53.009	56.028

*(N=24)

Table 27. Comparison of means for black males between Terry Collection and modern samples.

Variable	Left Terry (N=53)	Left Modern (N=30)	Right Terry (N=53)	Right Modern (N=30)
Age	45.77	42.21**	45.77	42.21**
Stature (ASTAT)	171.360	172.455	171.360	172.455
M1XL	49.804	50.290	50.277	50.953*
M1ML	49.304	49.263	49.542	49.636*
M2ML	71.147	72.553	71.198	72.653
M3ML	70.164	71.023	70.194	71.593
M4ML	62.302	63.597	62.204	64.070
M5ML	57.343	58.730	57.219	58.517

*(N=29)
**(N=28)

for the test sample are given in Tables 28 and 29. Three of the ten individuals have all of the estimates within one standard error of estimate. One of the individuals has stature estimates that are within one standard error of estimates with the exception of the one using right M5ML which is within three standard errors of estimate. Three individuals include estimates within both one and two standard errors. One individual has all of the stature estimates within two standard errors. The only individual that all of the estimates fall outside of two standard errors is a 25 year old white male. His stature is 188.5 cm, and all of the estimates are between 12.66 and 15.12 cm below the measured stature.

The test sample results indicate that the new stature estimation formulae yield satisfactory stature estimates from metacarpals.

Table 28. Stature estimates for test sample left side.

IDNO.	Age	Race	Stature	(Y-YHAT) Differences Between Known and Estimated Stature Using the Following Variables M1ML	M2ML	M3ML	M4ML	M5ML
UT1-90	69	White	168.8	-2.87	1.18	1.63	-	3.37
UT3-87	36	White	181.0	7.44	3.86	7.49	-	7.94
UT7-87	58	White	170.3	-9.54	-6.56	-9.40	-	-0.69
UT8-87	25	White	188.5	13.37*	14.15*	13.93*	-	15.12*
UT10-87	76	White	165.6	-0.11	2.46	0.09	-	2.88
UT5-88	55	White	176.1	-4.68	1.90	0.63	-	3.04
UT13-88	31	White	179.6	4.79	6.94	5.03	-	5.03
UT88-21	34	White	182.9	-	8.28	-	-	-
UT4-88	-	Black	168.2	-	-2.72	-1.10	0.50	-0.46
UT86-30	73	Black	180.3	-	3.68	3.51	6.04	9.04
Mean Differences				-0.51	5.03	2.42	3.27	5.03

*Estimate beyond two standard deviations.

Table 29. Stature estimates for test sample right side.

IDNO	Age	Race	Stature	(Y-YHAT) Differences Between Known and Estimated Statures Using the Following Variables			
				M2ML	M3ML	M4ML	M5ML
UT1-90	69	White	168.8	-	0.95	3.06	-13.33*
UT3-87	36	White	181.0	-	-	6.53	7.24
UT7-87	58	White	170.3	-	-10.62*	-6.15	-
UT8-87	25	White	188.5	-	12.90*	12.66*	15.52*
UT10-87	76	White	165.5	-	-2.25	0.93	-0.41
UT5-88	55	White	176.1	-	-0.41	3.32	0.79
UT13-88	31	White	179.6	-	-	-	-
UT88-21	34	White	182.9	-	5.63	6.90	-
UT4-88	--	Black	168.2	-0.27	-1.89	-1.83	-2.60
UT86-30	73	Black	180.5	4.64	-	-	-
Mean differences				2.19	0.62	3.18	14.24

*Estimates beyond two standard deviations.

CHAPTER VI

DISCUSSION AND CONCLUSION

Estimation of adult stature from the lengths of metacarpals has been examined previously by Musgrave and Harneja (1978) with moderate results using an English sample. The present research has examined the strength of the relationship between metacarpal length and stature using two different American samples, the Terry Collection (N=212) and a modern sample (N=45), as well as a combination of the two samples. Regression equations allowing stature estimation from metacarpal lengths have been given for the Terry Collection and for the combined sample. The regression equations based on the combined sample is only for white and black males. A test sample of ten males (8 white, 2 black) from a modern collection have been employed to test the new stature equations.

The results of the study show that the null hypothesis that metacarpal length has no correlation with stature must be rejected. The test hypothesis that metacarpal length is correlated with stature and that stature can be predicted based on the lengths of metacarpals is accepted. The strengths of the relationships between metacarpal length and stature (see Tables 13 and 14) are quite high ranging from .582 to .828 for the left side and .565 to .811 for the

right side in the Terry Collection. The modern sample reveals strengths not as high (see Table 21) ranging from .408 to .686. This is probably a result of the small sample sizes of 25 whites and 30 blacks. The correlation coefficients for the modern white sample are very low and even insignificant, again reflecting not the actual strengths but the very small sample size.

When the correlation coefficients from this study are compared with those given by Musgrave and Harneja (1978), ranging from .53 to .67 for males, this sample exhibits slightly stronger relationships between the metacarpal lengths and stature. The sample Musgrave and Harneja used includes 53 left and 67 right hands of white European males (1978), while the sample of this study includes both left and right hands of black (N=83) and white (N=81) males. Another problem with Musgrave and Harneja's sample is that it only includes hands that sustained some type of injury requiring radiography. These sample discrepancies might account for the differences in the strengths of the correlations.

Regression equations allowing stature estimation from metacarpal lengths have been calculated for modern American males (see Tables 22 and 23). When comparing these equations to the equations provided by Musgrave and Harneja (1978) for males, the standard errors of estimate are smaller in this study ranging from 4.68 to 5.97 cm while

their range is from 5.49 to 6.30 cm. Overall, the present study is an improvement over that done by Musgrave and Harneja. The sample employed is based on an American population so that it can now accurately be applied to an American population, and the sample now also includes black males.

The equations were tested using ten modern males of known sex, race, and stature from the skeletal collection at the University of Tennessee, Knoxville, so that any gross errors in the new equations might be seen and adjustments made. The results of the test sample (see Tables 26 and 27) indicated that the new formulae are estimating stature usually within one or two standard errors of estimate. Based on these results, no adjustments need to be made on these equations.

While the new equations need no adjustments, improvement could be made by increasing the modern sample and excluding the Terry sample. This would enable equations to be calculated from all of the metacarpals. The modern sample would also be improved if the sample measurements were made on the actual bones, thus eliminating any parallax adjustments. While this study provides equations that can be used on modern individuals, it is restricted to males and only left and right metacarpals two through five. A modern American female sample needs to be acquired so that regression equations can be calculated for female stature

estimation.

In a forensic setting, stature is one of the many variables examined in skeletal analysis. The formulae available for stature estimation are numerous including formulae employing the long limb bones, vertebral column, foot bones, hand bones, and others. It is emphasized that the bones available for stature estimation be used in order of reliability or strength of correlation with stature. The long limb bones are the more highly correlated skeletal elements, and the hand and foot bones are among the moderately correlated elements with stature. However, often in the forensic setting, the more highly correlated elements are not recovered and are not available for analysis. This is what makes this study valuable. It is important to have stature estimation formulae using a wide variety of skeletal elements so that when complete recovery of the remains is not possible, the skeletal analysis can be as complete as possible in order to obtain a positive identification.

While it is important to improve this study, it has shown that metacarpals do have a moderately high correlation with stature. Modern samples are necessary for the sample improvement so that white and black females can be incorporated. The increased modern sample will also enable all ten of the metacarpals to be employed for equations.

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APPENDIXES

Appendix 1. Recording sheet for metacarpal measurements.

METACARPAL AND PHALANGE MEASUREMENT FORM — Meadows - Thesis

ID/CASE #:__________ AGE:______ SEX:_____ RACE:_____ RECORDER:________ DATE:____/____/____

CURATOR:____________ STATURE: ______ / _______ (cm./in.) MEANS OF STATURE: ____________ FDN: _____

METACARPAL	I L	I R	II L	II R	III L	III R	IV L	IV R	V L	V R
MXL (total)	____.__	____.__	____.__	____.__	____.__	____.__	____.__	____.__	____.__	____.__
MXL (mid)	____.__	____.__	____.__	____.__	____.__	____.__	____.__	____.__	____.__	____.__
A-P dia.	____.__	____.__	____.__	____.__	____.__	____.__	____.__	____.__	____.__	____.__
M-L dia.	____.__	____.__	____.__	____.__	____.__	____.__	____.__	____.__	____.__	____.__
Palmar MXB	____.__	____.__	____.__	____.__	____.__	____.__	____.__	____.__	____.__	____.__
Dorsal MXB	____.__	____.__	____.__	____.__	____.__	____.__	____.__	____.__	____.__	____.__

Appendix 2. Radiography specifications and protocol.

Bennett X-Ray
Machlett Collimaster M
Type 42
Focus 1-2
Catalog S-21223
Serial P-24359
Insert -HD40

-Warm up x-ray machine and run a few old x-rays through the machine
-shoot x-ray with film 30" (76cm) from cone (table height designated on x-ray stand with cone all the way up)
-shoot palms up (to be sure bones are as close to film as possible)
-cassette must have standard taped to it for scale

-settings: KV-60 MA-100 SEC-1/120

-documentation: label each x-ray with case number and hand side as follows:

left or right
case no.
race/sex/age

envelope label

case no.
height in centimeters
(measured in calipers)
race/sex/age
date
list handedness and occupation (if known)

-place x-rays into envelope and store in x-ray box in small exam room

Appendix 3. Recording forms for x-ray measurements.

X-RAY Measurement Data Sheet Meadows - Thesis

IDNO________ STATURE (cm)______

AGE_____ SEX_____ RACE_____

Measurement	LEFT	RIGHT	Measurement	LEFT	RIGHT
MC1 max. length	___.__	___.__	MC3 mid. length	___.__	___.__
MC1 mid. length	___.__	___.__	MC4 mid. length	___.__	___.__
MC2 mid. length	___.__	___.__	MC5 mid. length	___.__	___.__

Comments:

Appendix 4. Abbreviated terms.

1. M1XL - Metacarpal I, maximum length.*

2. M1ML - Metacarpal I, midline length.*

3. M2XL - Metacarpal II, maximum length.

4. M2ML - Metacarpal II, midline length.

5. M3XL - Metacarpal III, maximum length.

6. M3ML - Metacarpal III, midline length.

7. M4XL - Metacarpal IV, maximum length.

8. M4ML - Metacarpal IV, midline length.

9. M5XL - Metacarpal V, maximum length.

10. M5ML - Metacarpal V, midline length.

11. ASTAT - Age adjusted stature of the modern sample.

12. Stature - Age adjusted stature of Terry Collection sample.

*Lengths are illustrated in Figure 1 of text.

Appendix 5. Correlation coefficients for white males and females left side. Males are above the diagonal.

	AGE	STAT	M1XL	M1ML	M2XL	M2ML	M3XL	M3ML	M4XL	M4ML	M5XL	M5ML
AGE	1.000	-0.228	-0.168	-0.185	-0.151	-0.154	-0.210	-0.203	-0.144	-0.165	-0.208	-0.201
STAT	-0.101	1.000	0.658	0.659	0.801	0.809	0.805	0.825	0.828	0.816	0.747	0.780
M1XL	0.173	0.677	1.000	0.990	0.831	0.834	0.798	0.808	0.826	0.824	0.829	0.825
M1ML	0.194	0.667	0.993	1.000	0.846	0.851	0.813	0.817	0.832	0.830	0.844	0.840
M2XL	0.124	0.787	0.810	0.815	1.000	0.987	0.928	0.931	0.911	0.905	0.869	0.878
M2ML	0.113	0.788	0.822	0.824	0.988	1.000	0.938	0.946	0.927	0.919	0.899	0.909
M3XL	0.165	0.694	0.780	0.786	0.918	0.921	1.000	0.960	0.916	0.902	0.880	0.897
M3ML	0.117	0.746	0.813	0.824	0.950	0.952	0.954	1.000	0.944	0.936	0.894	0.913
M4XL	0.126	0.701	0.807	0.807	0.921	0.920	0.904	0.948	1.000	0.989	0.906	0.942
M4ML	0.099	0.711	0.806	0.805	0.919	0.922	0.903	0.946	0.993	1.000	0.895	0.932
M5XL	0.106	0.667	0.827	0.816	0.867	0.884	0.848	0.870	0.912	0.925	1.000	0.984
M5ML	0.096	0.685	0.836	0.826	0.891	0.909	0.858	0.891	0.935	0.946	0.989	1.000

Appendix 6. Correlation coefficients for white males and females right side. Males are above the diagonal.

	AGE	STAT	M1XL	M1ML	M2XL	M2ML	M3XL	M3ML	M4XL	M4ML	M5XL	M5ML
AGE	1.000	-0.228	-0.175	-0.188	-0.174	-0.163	-0.164	-0.138	-0.156	-0.179	-0.279	-0.278
STAT	-0.101	1.000	0.618	0.641	0.791	0.790	0.756	0.785	0.816	0.811	0.656	0.704
M1XL	0.150	0.701	1.000	0.989	0.837	0.848	0.780	0.785	0.790	0.808	0.785	0.798
M1ML	0.165	0.704	0.990	1.000	0.840	0.856	0.779	0.784	0.796	0.818	0.791	0.803
M2XL	0.156	0.779	0.852	0.859	1.000	0.990	0.922	0.931	0.923	0.930	0.829	0.846
M2ML	0.137	0.779	0.848	0.853	0.992	1.000	0.929	0.932	0.930	0.938	0.845	0.860
M3XL	0.178	0.692	0.809	0.820	0.932	0.927	1.000	0.961	0.892	0.897	0.829	0.832
M3ML	0.181	0.710	0.845	0.849	0.958	0.956	0.972	1.000	0.916	0.925	0.827	0.837
M4XL	0.100	0.697	0.839	0.847	0.920	0.919	0.924	0.959	1.000	0.991	0.859	0.893
M4ML	0.080	0.724	0.844	0.851	0.924	0.923	0.921	0.953	0.994	1.000	0.875	0.907
M5XL	0.088	0.631	0.792	0.804	0.857	0.865	0.851	0.872	0.915	0.926	1.000	0.984
M5ML	0.096	0.640	0.806	0.815	0.878	0.883	0.870	0.894	0.934	0.947	0.988	1.000

Appendix 7. Correlation coefficients for black males and females left side. Males are above the diagonal.

	AGE	STAT	M1XL	M1ML	M2XL	M2ML	M3XL	M3ML	M4XL	M4ML	M5XL	M5ML
AGE	1.000	-0.193	-0.085	-0.050	-0.115	-0.120	-0.153	-0.162	-0.185	-0.180	-0.142	-0.190
STAT	-0.029	1.000	0.645	0.627	0.672	0.676	0.616	0.613	0.582	0.599	0.606	0.604
M1XL	0.034	0.646	1.000	0.989	0.782	0.810	0.762	0.753	0.803	0.794	0.794	0.790
M1ML	0.027	0.648	0.989	1.000	0.755	0.784	0.741	0.730	0.785	0.776	0.780	0.772
M2XL	0.031	0.611	0.835	0.824	1.000	0.988	0.910	0.927	0.903	0.908	0.911	0.905
M2ML	0.015	0.613	0.830	0.819	0.993	1.000	0.923	0.941	0.905	0.915	0.908	0.902
M3XL	0.106	0.659	0.799	0.789	0.918	0.904	1.000	0.982	0.945	0.952	0.913	0.904
M3ML	0.058	0.671	0.819	0.810	0.935	0.928	0.975	1.000	0.951	0.962	0.918	0.912
M4XL	-0.050	0.669	0.810	0.813	0.884	0.886	0.919	0.940	1.000	0.991	0.935	0.934
M4ML	-0.063	0.677	0.819	0.820	0.879	0.880	0.923	0.940	0.992	1.000	0.944	0.942
M5XL	0.056	0.615	0.775	0.767	0.849	0.833	0.898	0.890	0.908	0.909	1.000	0.987
M5ML	0.031	0.611	0.785	0.777	0.857	0.844	0.906	0.898	0.922	0.923	0.990	1.000

Appendix 8. Correlation coefficients for black males and females right side. Males are above the diagonal.

	AGE	STAT	M1XL	M1ML	M2XL	M2ML	M3XL	M3ML	M4XL	M4ML	M5XL	M5ML
AGE	1.000	-0.193	-0.083	-0.063	-0.129	-0.128	-0.123	-0.101	-0.164	-0.142	-0.114	-0.179
STAT	-0.029	1.000	0.668	0.653	0.646	0.655	0.565	0.572	0.608	0.615	0.616	0.591
M1XL	0.053	0.660	1.000	0.989	0.823	0.852	0.806	0.796	0.830	0.830	0.821	0.825
M1ML	0.054	0.668	0.989	1.000	0.793	0.826	0.776	0.761	0.811	0.810	0.800	0.807
M2XL	0.056	0.650	0.839	0.840	1.000	0.983	0.892	0.920	0.909	0.904	0.919	0.919
M2ML	-0.020	0.641	0.805	0.803	0.944	1.000	0.901	0.926	0.905	0.910	0.912	0.920
M3XL	0.079	0.676	0.805	0.787	0.896	0.848	1.000	0.983	0.933	0.930	0.904	0.910
M3ML	0.094	0.698	0.812	0.800	0.929	0.881	0.975	1.000	0.939	0.937	0.906	0.914
M4XL	-0.055	0.609	0.722	0.718	0.785	0.743	0.827	0.847	1.000	0.994	0.926	0.934
M4ML	-0.041	0.614	0.740	0.735	0.799	0.760	0.848	0.861	0.992	1.000	0.932	0.940
M5XL	0.015	0.619	0.785	0.776	0.841	0.774	0.866	0.871	0.838	0.854	1.000	0.978
M5ML	-0.027	0.634	0.784	0.778	0.871	0.813	0.880	0.893	0.867	0.879	0.987	1.000

VITA

Lee was born in Knoxville, Tennessee, on December 3, 1962. She attended elementary and middle schools in Knox County, and she graduated from Farragut High School with honors in 1981.

In the fall of 1982, Lee entered the University of Tennessee, and spent three years as an undergraduate majoring in business. In 1985, she became interested in anthropology and spent the next two years as an undergraduate majoring in anthropology. Spring of 1987, Lee received a Bachelor of Arts with honors.

In the fall of 1988, Lee began her graduate studies at the University of Tennessee, and she was awarded the Master of Arts degree in Anthropology in May 1990. Lee has been accepted into the doctoral program at the University of Tennessee, and she plans to pursue this next step in her graduate studies.

Lee's main areas of interest include forensic anthropology, skeletal biology, and historic population studies. Professional memberships include Sigma Xi, American Academy of Forensic Sciences, and Tennessee Anthropological Association.