STATURE WARS: WHICH STATURE ESTIMATION METHODS ARE MOST APPLICABLE TO MODERN POPULATIONS?

THESIS

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Elizabeth T. Brandt, B.A.

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STATURE WARS: WHICH STATURE ESTIMATION METHODS ARE MOST APPLICABLE TO MODERN POPULATIONS?

Committee Members Approved:

Jerry Melbye, Chair

Elizabeth Erhart

M. Katherine Spradley

Approved:

J. Michael Willoughby
Dean of the Graduate College

DEDICATION

This is for you Georgie. Your friendship and loyalty will never be forgotten. You will always have a very special place in my heart and in my memories. May the trail never end...

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ABSTRACT

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by

Elizabeth T. Brandt, B.A.

Texas State University-San Marcos

May 2009

SUPERVISING PROFESSOR: JERRY MELBYE

The primary focus of this thesis is a comparison of the mathematical and anatomical methods commonly used to estimate living stature to determine which method gives the most accurate and reliable results when working with modern skeletal individuals in a North American forensic setting. Four primary stature estimation methods are compared: the regression equations of Trotter and Gleser (1952, 1958), FORDISC 3 (Jantz and Ousley 2005), the Fully method (1956) and the revised Fully method (Raxter et al. 2006). The modern study sample (n = 233) is drawn from American Blacks and American Whites of the Bass and Maxwell Collections. A secondary focus of this thesis concerns the adjustment factor (2.5 cm) suggested by Trotter and Gleser (1952) for the conversion of cadaver stature to living stature. This study demonstrates that this adjustment factor is not appropriate for use on the current study sample. This study also indicates that adequate comparisons of the four stature estimation methods can be made in the absence of such a conversion.

CHAPTER I

INTRODUCTION

In forensic anthropology, living (forensic) stature is among the four major categories of the basic biological profile: sex, age, ancestry and stature (Iscan 1988). One critical role of stature estimation today lies in the forensic identification of crime victims and missing persons. Anthropologists have investigated multiple bones of the body for potential use in stature estimation: long bones (Rollet 1889), cranial height (Ryan and Bidmos 2007), scapula, clavicle and os coxa (Shulin and Fangwu 1983), metacarpals (Musgrave and Harneja 1978), metatarsals (Byers et al. 1989), tarsals (Holland 1995), vertebrae (Nagesh and Kumar 2006). Even foot and shoeprint length are not exempt from scrutiny (Giles and Vallandigham 1991). Because of the incomplete and fragmentary nature of many remains, others have examined the possibility of estimating stature from just sections of long bones (Steele and McKern 1969, Simmons et al. 1990, Wright and Vasquez 2003).

At present, there are two major methods used to estimate stature: the mathematical method and the anatomical method. The mathematical method takes advantage of the high linear correlation between long bones and stature (Pearson 1899). With a long bone as the dependent or independent variable, one can utilize a regression equation that reflects the relationship between an individual’s stature and the chosen long bone. The anatomical method, more commonly referred to as the "Fully method", reconstructs stature by summing the measurements of the skeletal elements that contribute to height and adding a correction factor for soft tissue (Fully 1956).

In this study, four stature estimation methods are compared, two mathematical and two anatomical, to determine which method or methods are most reliable in estimating the living (forensic) stature of modern individuals. The idea for this study originated from work on a series of cold cases at Texas State University-San Marcos. When faced with the task of estimating stature and given a full complement of skeletal material, which method should one choose? Is it worth the extra time and effort to implement the anatomical methods? And if so, which one? Are both Fully methods, the original 1956 version and the revised 2006 version (Raxter et al.), equally adequate? How reliable is FORDISC 3 (Jantz and Ousley 2005) in estimating living stature? Thus far, the only information in the scientific literature regarding the effectiveness of FORDISC 3 deals with the skull and the estimation of ancestry. What about the 50 year-old regression equations of Trotter and Gleser (1952, 1958)? Despite their antiquity, are these equations still applicable to modern individuals? While the information gleaned from this study is specifically targeted for the accurate estimation of stature in forensic contexts, some aspects may be useful for the study of ancient populations as well.

Mathematical Methods

Regression Formulae Using the Femur (Trotter and Gleser 1952, 1958)

Rollet was the first to explore the correlation between long bone length and stature with a sample of 100 mixed-sex cadavers in 1889 (cf. Pearson 1899). He provided tables from which one could look up stature from long bone length, or vice versa. Pearson, using Rollet's data, produced the first regression equations for estimating stature from long bone lengths. He also cautioned researchers against using these equations for individuals outside of the reference population. Dupertuis and Hadden (1951) subsequently published the first regression formulae for American sub-groups. Trotter and Gleser (1952) published their renowned formulae the next year, followed by an updated publication with additional data in 1958.

Trotter and Gleser's (1952) stature study was groundbreaking for three major reasons. First, they were able to obtain reliable living and cadaver statures for their samples. Second, their total sample was very large, 5027 individuals, the majority of which was comprised of male soldiers from World War II (Trotter and Gleser 1952) and the Korean War (Trotter and Gleser 1958). Although the soldiers' antemortem statures were measured by various military personnel at numerous induction stations around the country, 1944 War Department Regulation stipulated that a soldier's height was to be measured without shoes against a vertical graduated board that was permanently attached to a horizontal measuring rod. Such uniformity in stature measurement was uncommon and extremely beneficial for the accuracy of their data and the outcome of their study. The remainder of their sample (855 men and women) was taken from the Terry Collection, which contains unclaimed cadavers from the lower socioeconomic classes of Missouri (Hunt and Albanese 2005). The average birth period for this group was the early 1880s.

Trotter and Gleser (1970) recorded the maximum length of all long bones on each subject: femur, tibia, fibula, humerus, radius and ulna, to calculate the mean measurement of each pair. They then plotted these bone lengths with their corresponding stature measurements to ascertain a “best fit” regression line, and they published stature estimation formulae of all long bones for: American White males, American White females, American Black males, American Black females, Hispanic American males and American “Mongoloid” males. Each formula was accompanied by its standard deviation. Although the standard deviations varied slightly from one long bone to the next and from one sub-group to the next, they demonstrated that the weight-bearing bones of the lower limbs have the highest correlation with stature and advised against the use of upper limb bones unless lower limb bones are not available (Trotter and Gleser 1958).

The third reason that Trotter and Gleser’s (1952) work was groundbreaking is that they addressed the aging factor and its effect on stature estimation. Hooten attributed age-related stature loss primarily to degeneration of the spinal column, a progressive flattening of the centra and the cartilaginous discs (cf. Trotter and Gleser 1951). Similarly, the cartilage in weight-bearing joints may be flattened, but he noted no change in long bone length. Based on the findings of previous researchers, Trotter and Gleser selected the age of thirty as the general point at which a decrease in stature is generally first noted. In their study, they observed a steady decrease of 0.06 cm per year, relatively consistent across sexes and ancestral groups. However, they did note an unusually acute decrease in the stature of White females between the age of eighty and ninety.

FORDISC (Version 3) (Jantz and Ousley 2005)

FORDISC 3 is the most recent edition of a windows-based computer software program, developed by Jantz and Ousley (2005) to enable forensic anthropologists to estimate the sex, ancestry and stature of adult cranial and postcranial elements. The Forensic Anthropology Data Bank (FDB) provides the data for FORDISC 3, and currently contains measurements provided by universities, medical examiners and forensic agencies for about 2900 modern American individuals, of which 1731 are positively identified (http://web.utk.edu/~fac/databank.shtml). This program estimates stature using linear regression “on the fly”. This means that the estimate given depends upon the number and type of skeletal elements used in the calculation. Regression is used in the estimation process in a dynamic and individualized manner, instead of in the set, static manner of regression equations.

Anatomical Methods

Original Fully Method (1956)

Anatomical methods of stature estimation provide a direct reconstruction of height by summing the measurements of the skeletal elements that contribute to stature (Appendix B) and adding a correction factor for soft tissue and skin. Dwight piloted this method in1894 (cf. Lundy 1985). Dwight laid a skeleton out on a table in anatomical position and used clay as an interstitial proxy for soft tissue. He then measured the stature of the finished product, estimating 32 mm for the average accumulated length of the soft tissue.

Fully (1956) approached the method from a slightly different perspective. Working with a sample of 60 French soldiers, he measured each skeletal element independently: cranial height, vertebral height (the second cervical through the first sacral vertebrae), bicondylar femoral length, maximum tibia length (without eminence), and the articulated height of the calcaneus and talus. He then summed the measurements to obtain skeletal height and added a soft tissue correction factor to estimate living stature. To calculate the soft tissue correction factor, he subtracted the average living stature of his sample (taken from military records) from the average skeletal height. This gave him an average difference of 10.5 cm, which Fully assessed to be the soft tissue estimate for an individual of average stature. He recommended two other figures for those at short and tall extremes (10.0 cm and 11.5 cm respectively).

Adjusted Fully Equation and Age Correction Factor (Raxter et al. 2006)

Thus far, very few studies have questioned the integrity of the Fully method or compared its accuracy against other stature estimation methods (Lundy 1988, Bidmos 2005). Recently, Raxter et al. (2006) tested Fully's method (1956) using a large documented sample (n = 119) from the Terry collection that consisted of males and females, American Whites and Blacks, aged 21-85 years. They noted a discrepancy between the soft tissue correction factor of Fully's sample (10.5 cm) and their own (12.4 cm). Raxter et al. (2006) also discovered that Fully's original equation tended to underestimate living statures (adjusted cadaver statures) in their sample. However, when they applied Trotter and Gleser's age correction factor of 0.06 cm per year for individuals over the age of 30, this adjustment resulted in an overestimation of stature. Thus, they settled on an age adjustment factor of 0.0426 cm per year and generated new equations based on whether or not age is known. It is important to note that Raxter et al. converted cadaver statures to estimated living statures in their sample by subtracting 2.5 cm as suggested by Trotter and Gleser (1952).

The Issue of Cadaver Stature versus Living Stature

Manouvrier first noted a discrepancy between living stature and cadaver stature; he recommended that 2.0 cm be subtracted from cadaver stature to obtain an individual's living stature (cf. Lundy 1985). He postulated that this difference was due to the compression of soft tissues when a living person stands erect. Trotter and Gleser (1952) noted an average decrease of 2.5 cm between cadaver and living statures. Correa (1932) and Telkka (1950) noted a consistent discrepancy of 2.0 cm (c.f. Genoves 1967). Pearson (1899) noted a difference between females (2.0 cm) and males (1.2 cm). Conversely, some researchers did not agree that there is a noticeable difference between living stature and cadaver stature (Dupertuis and Hadden 1951). Thus, there does not appear to be a standard, empirically-proven formula for the conversion of cadaver stature to living stature.

Trotter and Gleser's 2.5 cm Adjustment Factor for Converting Cadaver Stature to Living Stature

Of all the suggested increments for the conversion of cadaver stature to living stature (and vice versa), Trotter and Gleser's (1952) recommendation of 2.5 cm has been most often utilized by researchers (Genoves 1967, Bidmos 2005, Raxter 2006). Trotter and Gleser (1952) calculated this 2.5 cm adjustment factor from two American White, male only, sub-samples of the same population from which they derived their regression equations used to estimate stature. The adjustment factor was calculated in a relatively complex and indirect manner. The first sub-sample represented 3527 young soldiers (long bones and known antemortem statures). The second sub-sample represented 255 civilians of all ages (long bones and known cadaver statures). Regression equations were developed for the men, as a group, based on the measurements of their long bones. Trotter and Gleser then used these equations to estimate the information that they did not have for both groups: cadaver statures for the soldiers and living statures for the civilians. The latter were additionally adjusted for age. Thus, the calculations consisted of the following:

Soldiers (n = 3527): estimated cadaver stature - known living stature = 2.69 cm.
Civilians (n = 255): known cadaver stature - estimated living stature (adjusted for age) = 2.35 cm.

The two results were subsequently averaged to obtain 2.5 cm.

Because of the sub-samples used to derive this adjustment factor, as well as the methodology, it needs to be examined to determine its applicability to the present sample. The adjustment factor is supposed to compensate for the expansion of intervertebral soft tissue after death. However, do all individuals have the same amount of soft tissue? Does everyone’s stature undergo equal expansion upon death? Is the 2.5 cm correction factor of a tall, young man equally applicable for a five foot tall elderly woman? These are the types of questions that will be explored in this study pertaining to the utilization of a stature conversion factor.

Thesis Focus

The primary focus of this thesis was a comparison of the mathematical and anatomical methods commonly used to estimate living stature to determine which method gives the most accurate and reliable results when working with modern skeletal individuals in a North American forensic setting. While the primary emphasis of this study was the estimation of stature of modern individuals, the information derived can certainly be useful in other contexts, such as historical or bioarchaeological.

The second question addressed in this study examined the 2.5 cm adjustment factor recommended by Trotter and Gleser (1952). All four stature estimation methods analyzed in this study are designed to estimate living stature. However, only cadaver stature was available for the present sample. Is the 2.5 cm adjustment appropriate for this study sample? If not, is it still possible to adequately compare the above four stature estimation methods without an adjustment?

CHAPTER II

MATERIALS and METHODS

About the Study Sample

Two modern skeletal collections were targeted for this study: the William M. Bass Collection at the University of Tennessee and the Maxwell Collection at the University of New Mexico. Each collection curator compiled a list of the individuals in their collection that met the specific criteria for the proposed research: adult individuals of known sex, age, ancestry and stature (cadaver and/or living) that had a relatively intact cranium and a majority of post-cranial elements.

As of June 2008, the Maxwell Collection was comprised of 262 individuals. Of this group, 71 were confirmed by the collection staff via a database, as having the potential for meeting the study criteria. However, after a visual examination, 29 individuals were excluded due to severely damaged, pathological and/or missing elements; the remaining 42 were measured and included in the study. These included 30 males and 12 females, ranging in age from 34 to 95 years. All are American White, except for one American Black and one Hispanic American. Of the 42 individuals, 33 had a cadaver stature, and the remaining nine had a living (forensic) stature. Demographic information on each individual was provided by the Maxwell staff after the completion of data collection.

From the Bass Collection only individuals from the donated collection were used because the forensic collection was not available at the time of data collection. As of July 2008, the donated collection was very large, containing 705 individuals. Of these, a listing of 431 skeletons was provided that potentially met the research criteria. The list was worked in order from the most recent donations (2007) to the oldest (1983). As with the Maxwell collection, damaged, incomplete and severely pathological individuals were rejected. The demographic breakdown for the Bass population sample of 193 was: 120 males and 73 females between the ages of 24 and 96 years, 170 American Whites, 22 American Blacks and one Hispanic American. All 193 individuals in the Bass sample had a cadaver stature and 31 had a living (forensic) stature listed as well.

In addition to the Bass and Maxwell collections, data were obtained from a local Texas forensic case, a 25 year-old American Black female. This brought the total number of individuals in the study sample to 236. The combined demographic profile of the entire study population is reflected in Table 1.

Table 1: Demographic Profile of Study Sample

	White American		**Black American**		**Hispanic American**		**Sub-total**		**Total**
	M	F	M	F	M	F	M	F	ALL
Number	129	81	20	4	1	1	150	86	236
Age range	26-96	32-95	23-84	25-59	24	81	23-96	25-95	23-96
Avg. Age	59.78		52.13		52.5		55.77	64.48	58.94

Preparation for Data Collection

To facilitate the data collection process, a “Data Recording Sheet” was maintained on each skeletal individual (Appendix A). The sheets for the Maxwell individuals included a preprinted "MAX" across the top, while those for the Bass individuals displayed "BASS". The initial section was dedicated to demographic information: sex, age, ancestry, stature and source of stature. The main body provided spaces to record all the necessary skeletal measurements to calculate the Fully method: cranium, vertebrae, S1, lower long bones and tarsals. It also provided a space to record the maximum length of the femur, necessary for the calculation of stature using Trotter and Gleser's equations and FORDISC 3. Finally, there was ample room at the bottom for the recording of additional notes and observations.

Upon the initial examination of each individual, a general inventory was performed to assess the potential of the remains for inclusion in the study (completeness, condition, etc.). If deemed a suitable candidate, the individual's assigned accession number was immediately recorded at the top of the data recording sheet along with the demographic information written on the side of the storage container. Once recorded, the information was cross checked with both the individual's container and the list provided by the collection manager to ensure that all data correctly matched.

The Measurement Procedure

Each set of skeletal remains was subjected to 33 measurements. "Revision of the Fully Technique for Estimating Statures" by Raxter et al. (2006) served as the basis for the measuring techniques employed to maintain consistency throughout the entire sample. Appendix B contains an illustrated description of the measurement procedure used in this study, as well as accompanying issues and/or problems, and how they were dealt with. All measurements were rounded to the nearest whole millimeter. Individuals who exhibited an unreasonable amount of trauma and/or pathology were not included in the study (ex: multiple fractures or bilateral limb replacement). A moderate amount of pathology was not considered as an obstacle in this study.

Mathematical and Anatomical Methods

Regression Formulae Using the Femur (Trotter and Gleser 1952, 1958)

The stature regression formulae of Trotter and Gleser are dependent upon sex and ancestry. Therefore, it was necessary to select the appropriate formula for each individual in the sample. The formulae of Trotter and Gleser were applied to the maximum length of the femur (Table 2). Meadows and Jantz (1995) suggest the use of the femur over that of the tibia due to its decreased level of proportional variation. No equation was available for the Hispanic American female measured in this study; therefore, this individual's data could not be used in this particular method and was removed from the sample, along with the Hispanic male, reducing the sample size to 234.

Table 2: Trotter and Gleser's Stature Regression Equations (1952, 1958)

ANCESTRY/SEX	FORMULA (cm)	INDIVIDUALS IN SAMPLE
American White male	2.32 x femur + 65.53 (+/- 3.94)	129
American White female	2.47 x femur + 54.10 (+/- 3.72)	81
American Black male	2.10 x femur + 72.22 (+/- 3.91)	20
American Black female	2.28 x femur + 59.76 (+/- 3.41)	4

Additionally, Trotter and Gleser (1952) recommend the application of an age correction factor for any individual over the age of 30 years: 0.06 cm x (age - 30) to compensate for the loss of bone and tissue that takes place during the aging process. This factor was applied to the 229 individuals in the study over the age of 30.

FORDISC (Version 3) (Jantz and Ousley 2005)

FORDISC 3 is a windows-based computer software program that provides an estimation of ancestry, sex and stature based upon the amount of specific data one enters (standard cranial and postcranial measurements). It relies on modern data from the Forensic Anthropology Data Bank (FDB) (http://web.utk.edu/~fac/databank.shtml) in its estimations. Only the stature portion of the program was utilized for this study. The following information on each individual was entered into FORDISC 3:

- maximum length of femur
- bicondylar length of femur
- maximum length of tibia (without the eminence)
- sex
- ancestral affiliation

The FORDISC 3 users guide (2005) states that when applying this program to estimate stature, precision improves with additional measurements. For this study, only three long bone measurements were available for input into the program because only data required for the calculation of the Fully method and Trotter and Gleser's femur equations were collected. For optimal results, all skeletal elements should be utilized (FORDISC Users Guide 2005). The guide also stipulates that there is no need to adjust for age-related stature loss since the database uses forensic statures. Thus, no age adjustments were made. Finally, FORDISC 3 contains data on both 19th and 20th century individuals (FORDISC Users Guide 2005). It was prompted to consider only 20th century forensic statistics for this study because that group is the primary focus of this study. FORDISC 3's 20th century forensic statistics are compiled from the following: 141 American Blacks (87 males and 54 females), 252 American Whites (153 males and 99 females), and 31 Hispanic American males.

Original Fully Method (1956)

The estimated height of all individuals was calculated using the original Fully equation from 1956. This involved adding a blanket soft tissue correction factor to each individual's skeletal height. In this study, the skeletal measurement methods outlined in Raxter et al. (2006) were followed, and the skeletal height for each individual was obtained by summing the measurements of the following elements: cranium + (C2 thru C7) + (T1 thru T12) + (L1 thru L5) + S1 + average bicondylar length of the femora + average maximum length of the tibiae + average height of the articulated calcanei and tali. All measurements were obtained in millimeters; thus, the total skeletal height was calculated in millimeters and then converted to centimeters. If only one measurement of a paired set was available, this was used in place of the average. If an extra vertebra was present (i.e. T13 or L6), its measurement contributed to the calculation of skeletal height. Each individual's skeletal height (total sum of elements) was calculated twice to double-check for accuracy.

The following corrections were developed by Fully (1956). The appropriate equation was selected for each individual in the sample:

- Skeletal Height < or = 153.5 cm, add 10 cm
- Skeletal Height from 153.6 cm to 165.4 cm, add 10.5 cm
- Skeletal Height > or = 165.5, add 11.5 cm

It is imperative to note that the method of Fully (1956) is designed to account for natural changes in the skeleton due to age and pathology. Therefore, no additional age adjustments were made.

Adjusted Fully Equation with Age Correction Factor (Raxter et al. 2006)

Raxter et al. (2006) noted a discrepancy between the average soft tissue correction factor of Fully's 1956 sample (10.5 cm) and their own (12.4 cm). They devised new equations to correct for this soft tissue factor discrepancy, as well as for the gradual effects of age on stature. They estimated the stature of all individuals of known age with the following equation:

$$LS = 1.009 \times \text{Skeletal Height (cm)} - 0.0426 \times \text{Age} + 12.1$$

This formula was applied to all individuals in the present sample.

Recorded Stature of the Sample

All 234 individuals in this study were accompanied by a cadaver stature. Inquiries were made to the staff at each collection facility about the practices they employed in cadaver measurement. All cadavers in the University of New Mexico collection were measured upon arrival at the medical examiner's office (Potter pers comm.). Stature was obtained with the body in a supine position. A tape measure was used to measure the distance from heel to crown. Although various workers and students at the facility took measurements, all were advised to follow the same protocol. At the University of Tennessee, all donations are measured by various graduate students, but entered into the database by only one individual (Wilson, pers comm.). Measurements were made from heel to crown in the supine position using an anthropometer or ruler. It is not known to what extent rigor mortis or other postmortem factors interfered with the measurement process. The assumption is made that all cadavers were measured in a consistent and reliable manner at both facilities.

Statistical Methods and Analyses

All measurements and pertinent observations for each individual (n = 234) were entered onto an EXCEL spreadsheet, and then transferred to SPSS Student Version 15 software (2006). Because of the copious amounts of recording and calculating required for this study, it is entirely possible that errors have been made, despite the practice of careful methodology. Any errors that occur are likely to be random and unbiased.

Prior to conducting statistical tests, normality of the data set was confirmed via the use of Q-Q plots (Appendix C). Additionally, a scatter-plot was generated between skeletal height and cadaver stature to check for any possible outliers (Figure 1). One individual was detected outside of the general correlation pattern, with a stature of 208 cm, but a skeletal height of only 165 cm. A check of the original data recording sheet for this individual confirmed a cadaver stature of 82 inches (208 cm). This was most likely a recording error made by either the medical examiner's office or the collection staff. Thus, this individual was excluded from the study, resulting in a final sample size of 233 individuals.

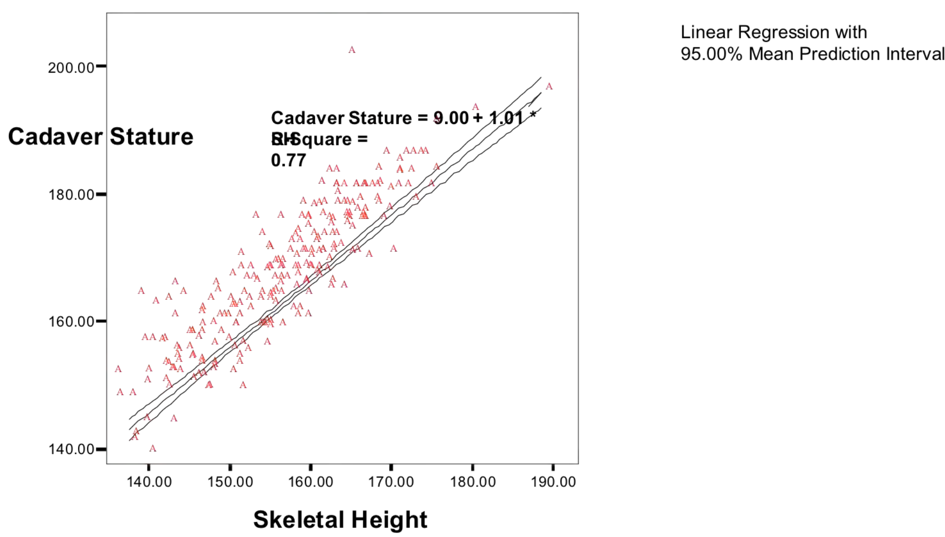


Figure 1: Scatter-Plot of Study Sample (Cadaver Stature vs. Skeletal Height)

Part I: The Question of Converting Cadaver Stature to Living Stature

While all individuals in the sample have a recorded cadaver stature, each of the four stature methods tested in this study estimate living (forensic) stature. Trotter and Gleser's (1952) recommendation of subtracting 2.5 cm from cadaver stature to obtain living stature has been the adjustment most often utilized by researchers (Genoves 1967, Bidmos 2005, Raxter 2006). The sample used by Trotter and Gleser in determining their soft tissue adjustment factor (STF) was American White, male and predominantly young. The present sample was of mixed ancestry, mixed sex and advanced in age. Thus, there was some concern that a subtraction of 2.5 cm may be too robust of an adjustment for the present sample. A series of statistical tests was used to examine the relationship between the amount of soft tissue in the present sample and age, sex, ancestry, stature and pathology to determine if 2.5 cm is an appropriate adjustment factor for the present sample.

Age and Soft Tissue

Hooten observed that age-associated stature loss resulted from the degeneration of the spine and a loss of intervertebral tissue (cf. Trotter and Gleser 1951). If older individuals possess less intervertebral tissue, it is logical to surmise that their bodies would experience less postmortem expansion. This would affect the amount of adjustment needed in converting cadaver stature to living stature. A series of regression analyses (males, females and combined) was used to check for any significant correlation between age and amount of soft tissue in the present sample. Additionally, a single-sample t test was used to compare the mean soft tissue factor of two sub-samples: the oldest 10% of the population (n = 23) and the youngest 10 % (n = 23). Soft tissue factor

(STF) was calculated for all individuals by subtracting skeletal height from cadaver stature.

Vertebral Pathology and Soft Tissue

One of the reasons stature tends to decrease with age is because of degeneration of the spine (Ortner 2003). Degenerative changes in the spine are not always age-related. Maladies such as ankylosing spondylitis, juvenile arthritis, scoliosis and tuberculosis can lead to severe vertebral modification, along with associated loss of soft tissue. In the present sample, the incidence of conjoined vertebral segments was noted during the measurement procedure. This permitted an analysis of the amount of soft tissue an individual possessed by the amount of vertebral pathology they displayed. A series of regression analyses (males, females and combined) was utilized to check for any significant correlation between the amount of vertebral pathology in the sample and STF.

Sex and Soft Tissue

There is no information found in the literature regarding sex and soft tissue. While men are on average generally taller than women (Guegan et al. 2000), it is not known if sex is a factor in the amount of soft tissue. An independent-samples t test was used to explore the differences in STF between males and females.

Stature and Soft Tissue

Similarly, one might expect taller individuals to possess more soft tissue than shorter ones. A simple regression test examined this correlation between STF and cadaver stature. Additionally, a one-sample t test was used to compare the mean amount of soft tissue of the tallest 10% of the sample ($n = 23$) and the shortest 10% ($n = 23$).

Ancestry and Soft Tissue

An independent-samples t test was used to compare the amount of soft tissue between American Whites and Blacks of this sample; due to the small sample size of American Black females, only males were compared in this test.

Part II: Comparison of the Four Stature Estimation Methods

In this study, an evaluation of the four stature estimation methods was made based upon patterns in the way each method estimated the recorded cadaver statures of the sample, as well as designated sub-groups of the sample.

Estimating Stature of the Entire Sample

One-sample t tests were utilized to compare the mean cadaver stature of the sample to the mean estimated living stature derived by all four stature estimation methods: Trotter and Gleser regression equations (1952, 1958), FORDISC 3 (Jantz and Ousley 2005), Fully method (1956), and Fully method (Raxter et al. 2006). A simple linear regression scatter plot is provided for each of the four relationships, indicating the R-square value of each of the four methods in the prediction of stature.

Extravertebral Sub-Sample

The present sample included a large number of individuals with extra vertebrae (n = 24) (Table 3). It should be noted that no individual in the sample has more than one extra vertebra. An extraneous lumbar vertebra is the most common configuration in this sample. The presence of an extra vertebra affects twice as many males as females, and nearly four times as many African Americans in this sample. If this number approximates the trend in the general population, it would be important to determine how sensitive stature estimation methods are in detecting and accurately estimating stature in these individuals. A single-sample t test was used to compare the mean cadaver stature of the extra-vertebral sub-sample to the living stature means estimated by the four methods.

Table 3: Extravertebral Sub-Sample

	Frequency of Occurrence
6th Lumbar	15
13th Thoracic	8
8th Cervical	1
Males w/extra vertebra	18 of 128 = 14%
Females w/extra vertebra	6 of 81 = 7%
Blacks w/extra vertebra	7 of 24 = 29%
Whites w/extra vertebra	17 of 209 = 8%
Entire Sample	24 of 233 = 10.3%

Short and Tall Sub-Samples

Mathematical methods of stature estimation are best suited for estimating the stature of people of average height because they are based on a population mean (Lundy 1985). The anatomical methods, on the other hand, are sensitive to variation stemming from differing body proportions because they base their estimates on all skeletal elements that contribute to stature (Lundy 1985). A single-sample t test was conducted to examine how accurately those at the extreme ends of the stature spectrum (very tall and very short) are estimated by all four stature estimation methods. For this test, the shortest 10% and tallest 10% of the sample were selected.

CHAPTER III

RESULTS

Note: the SPSS output of all statistical tests is available in Appendix C.

Part I: The 2.5 cm Adjustment Factor of Trotter and Gleser

Age and STF

A Pearson correlation coefficient was calculated for the relationship between age and STF in the present sample. A weak negative correlation was found for men ($n = 148$) ($r (146) = -.209$, $p = .011$), indicating a significant linear relationship between the two variables. Simply put, in this sample, older men tended to have less soft tissue. For females ($n = 85$), a weak correlation that was not significant was found ($r (83) = -.156$, $p = NS$). When the sexes are combined ($n = 233$), a weak negative correlation presides ($r (231) = -.188$, $p = .004$).

The mean STF of the youngest 10% of the sample (mean age 33 years, $n = 23$) was compared with that of the oldest 10% of the sample (mean age 87 years, $n = 23$). There was a large disparity between the soft tissue mean of the younger group (14.79 cm) and that of the older group (9.86 cm). A single-sample t test found this difference to be statistically significant ($t (22) = -4.496$, $p = .000$) (Table 4).

Vertebral Pathology and STF

A Pearson correlation coefficient was calculated for the relationship between vertebral pathology and STF. When sexes were combined (n = 233), it resulted in a weak negative correlation that was not significant (r (231) = -.108, p = NS). A weak but significant negative correlation was found for men (n = 148) (r (146) = -.186, p = .023), indicating a significant linear relationship between the two variables. Men with more fused vertebrae tend to have less soft tissue. For females (n = 85), a weak positive correlation that was not significant was found (r (83) = .051, p = NS).

Sex and STF

An independent-samples t test was calculated comparing the average STF of men (n = 148) and women (n = 85) (Table 4). No significant difference was found (t (231) = .554, p = NS).

Table 4: Soft Tissue Factor (STF)

Sub-sample	**Amount (cm)**
Sample Mean	12.26
All men	12.39
All women	12.02
White men	12.41
Black men	12.28
Oldest 10%	9.86
Youngest 10%	14.79
Tallest 10%	15.08
Shortest 10%	7.08

Stature and STF

A Pearson correlation coefficient was calculated for the relationship between cadaver stature and STF in the entire sample (n= 233). A weak positive correlation was found (r (231) = .205, p = .000), indicating a significant linear relationship between the two variables. This means that in the present sample, taller individuals tended to have more soft tissue than shorter ones. An independent-samples t test compared the differences in STF between the tallest 10 % of the sample (n = 23, mean stature 188.21 cm) and the shortest 10% of the sample (n = 23, mean stature 151.77 cm). A significant difference in STF was found between the two groups (r (22) = 8.91, p = .000) (Table 4).

Ancestry and STF

An independent-samples t test revealed that there were no statistically significant differences between the American Black males (n = 20) and American White males (n =128) in the present sample (t (146) = -.121, p = NS) (Table 4).

Part II: Comparison of the Four Stature Estimation Methods

Estimating Stature of the Entire Sample

Cadaver stature (without any adjustment) was used as a proxy for living stature in this study to compare the accuracy of four living stature estimation methods on a modern sample. The sample (n = 233) contained both men and women of American White and American Black ancestries, with an average age of 59 years. Single-sample t tests compared the mean cadaver stature of the sample (170.32 cm) to the mean living stature calculated by each of the four methods: Fully-1956 (168.61 cm), Fully-2006 w/age (169.07 cm), Trotter and Gleser (167.65 cm), and FORDISC 3 (170.77 cm). A significant difference was found for Fully-1956 (t (232) = -2.593, p = .010) and Trotter and Gleser (t (232) = -4.510, p = .000). This means that the living stature estimates of Fully (1956) and Trotter and Gleser (1952, 1958) were significantly different at a statistical level from the mean cadaver stature of the sample.

Table 5: Descriptive Statistics (in cm)

	N	Range	Minimum	Maximum	Mean	Std Dev	Variance
CADSTAT	**233**	**55.08**	**143.00**	**198.08**	**170.32**	**10.82**	**116.99**
F-1956	233	54.63	147.73	202.36	168.61	10.09	101.87
F-2006	233	54.80	147.53	202.33	169.07	9.93	98.66
T & G	233	42.54	147.25	189.79	167.65	9.04	81.63
FORDISC 3	233	46.00	149.50	195.50	170.77	9.45	89.32

A simple linear regression was calculated representing the relationship of each stature estimation method with the cadaver statures of the sample. The coefficients of determination (R-square values) provided an estimate of the proportion of the variance of cadaver stature that can be explained by variance in the estimation of each method (Figures 2, 3, 4 and 5).

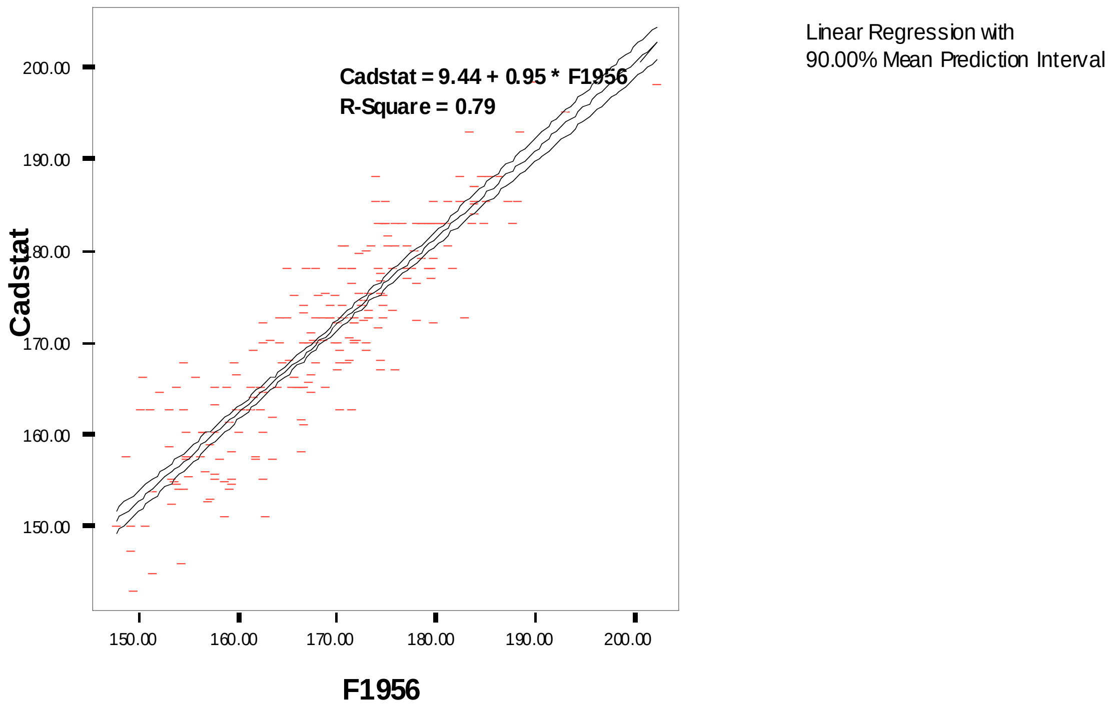


Figure 2: Fully-1956 vs. Cadaver Stature

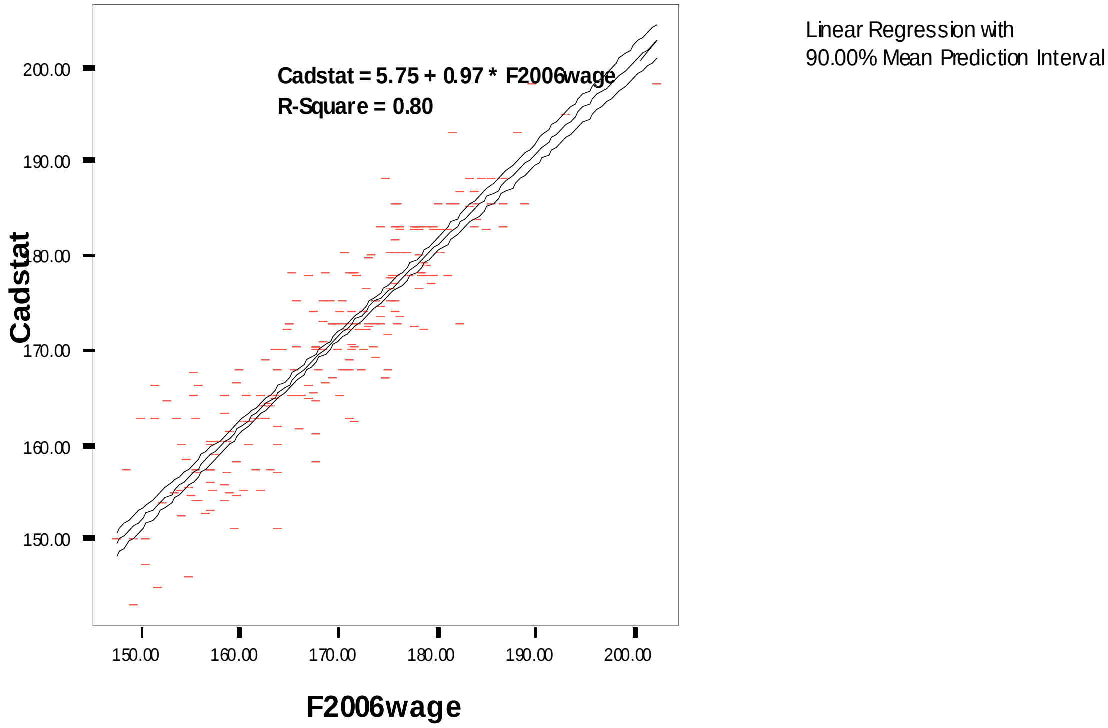


Figure 3: Fully-2006 (Raxter et al.) vs. Cadaver Stature

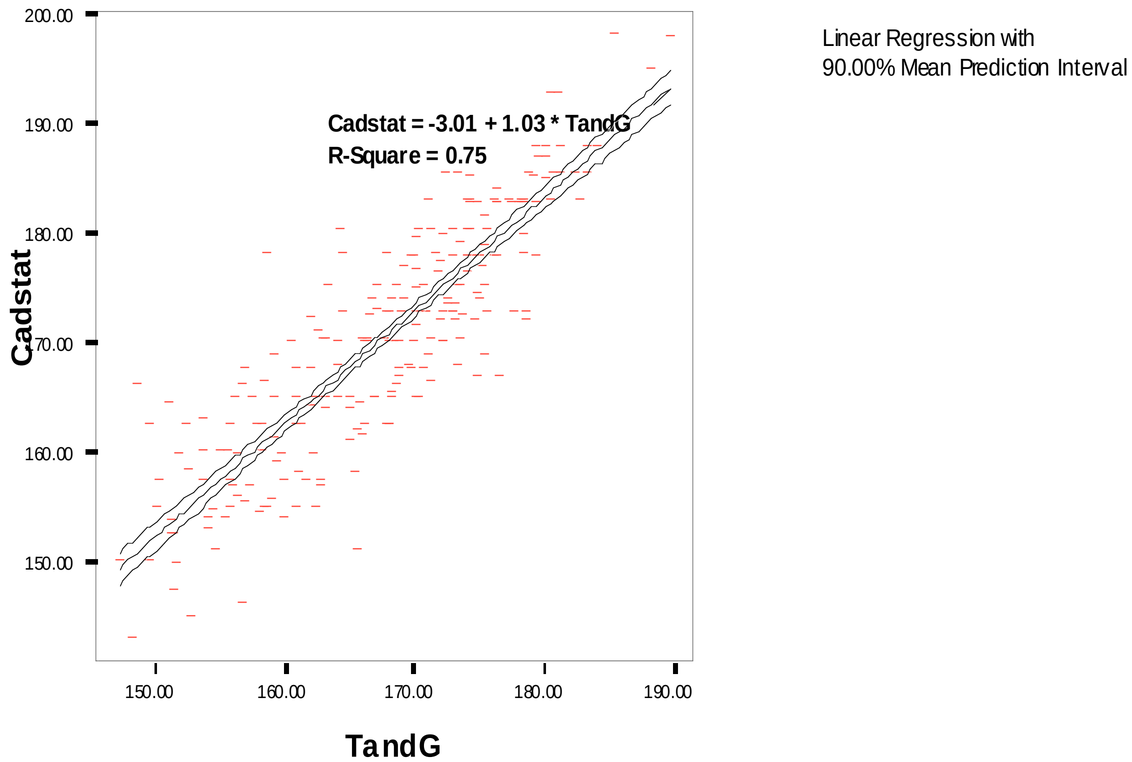


Figure 4: Trotter and Gleser (1952, 1958) vs. Cadaver Stature

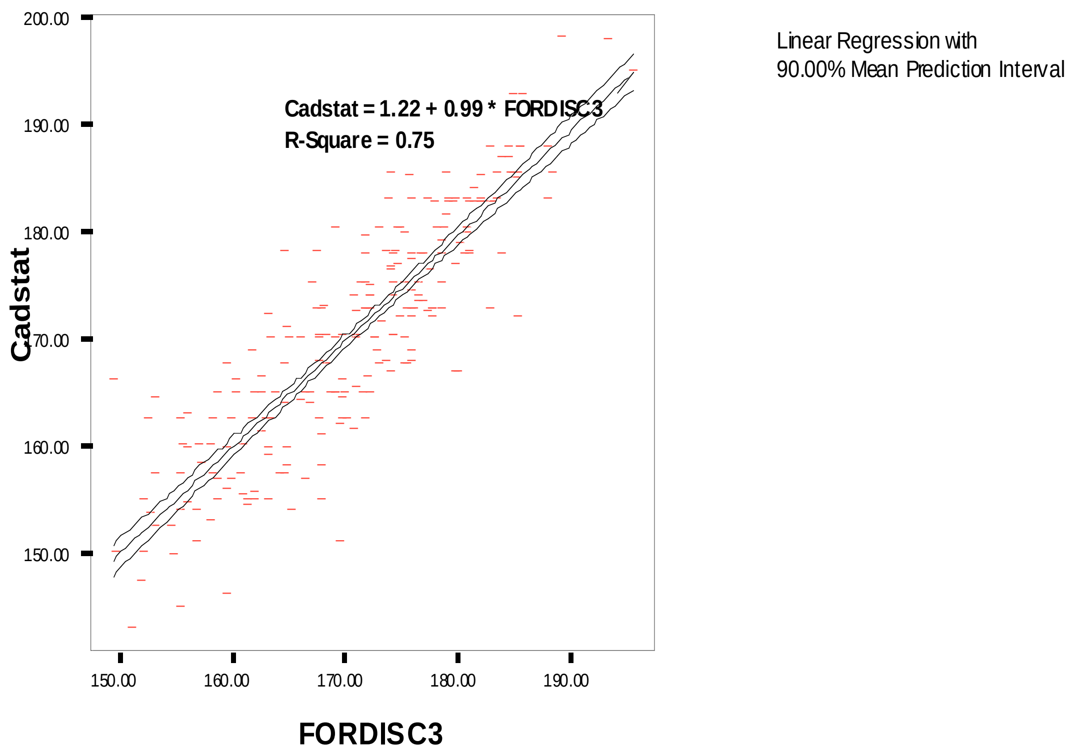


Figure 5: FORDISC 3 (Jantz and Ousley 2005) vs. Cadaver Stature

Estimating Stature of Those with Extra Vertebrae

A single-sample t test compared the mean stature (174.93 cm) of the extra-vertebral sub-sample (n = 24) with the mean stature estimations of the four methods (Table 6). A significant difference was found ($t(23) = -3.087$, $p = .005$). The mean stature estimated by the mathematical method of Trotter and Gleser (170.35 cm) was 4.58 cm less than the actual mean stature of the sub-sample (174.93 cm). The closest estimate of extravertebral stature was the revised Fully method 2006.

Table 6: Extravertebral Sub-Sample

Method	Distance from CADSTAT (cm)	P-value
F-1956	-1.297	NS
F-2006	- .856	NS
T & G	-4.581	.005
FORDISC 3	- .925	NS

<u>Estimating Those at Short and Tall Extremes</u>

Two sub-samples were examined to determine how sensitive the four stature estimation methods were to individuals at stature extremes. The first sub-sample consisted of the shortest 10% of the sample (n = 23) with an average stature of 151.77 cm. A paired-samples t test compared the mean stature of the sub-sample with the mean stature estimates of the four methods (Table 7). All of the means estimated by the methods were found to be significantly different from the sub-sample mean. Trotter and Gleser provided the closest estimate and FORDISC 3 was the most distant.

Table 7: Short Sub-Sample

Method	Distance from CADSTAT (cm)	P-value
F-1956	+ 2.922	.001
F-2006	+ 3.354	.000
T & G	+ 2.720	.008
FORDISC 3	+ 5.359	.000

A similar test examined the tallest 10% of the sample (n = 23) with an average stature of 188.21 cm. Once again, the estimates of all four methods differed significantly from the mean stature of the sub-sample (Table 8). Fully-1956, Fully-2006 and FORDISC 3 were all equidistant from the cadaver stature mean. The mean of Trotter and Gleser, however, was by far the most distant from the cadaver stature mean.

Table 8: Tall Sub-Sample

Method	Distance from CADSTAT (cm)	P- value
F-1956	- 3.705	.001
F-2006	- 3.633	.001
T & G	- 7.512	.000
FORDISC 3	- 3.495	.000

CHAPTER IV

DISCUSSION

The 2.5 cm Adjustment Factor (Trotter and Gleser 1952)

This study compared the accuracy of four stature estimation methods that are designed to estimate living stature. The skeletal sample for this study comes with documented cadaver statures. Researchers are undecided if these two types of stature (cadaver and living) are different, and if so, by what amount (Pearson (1899), Dupertuis and Hadden (1951), Trotter and Gleser (1952), and Correa and Telkka (cf Genoves 1967)). Trotter and Gleser (1952) advised a 2.5 cm blanket adjustment to obtain living stature from cadaver stature. Unlike the other researchers, their recommendation was based on a very large sample (n = 3782) and numerous scholars have utilized this adjustment factor when faced with a situation in which only cadaver statures were available (Genoves 1967, Bidmos 2005, Raxter 2006).

Age and Vertebral Pathology

There exists a concern that the 2.5 cm conversion factor proposed by Trotter and Gleser (1952) may not be appropriate for the present sample because the sample used by Trotter and Gleser to create the adjustment factor was very different from the present sample. Age and its associated vertebral degeneration is the primary difference between the two samples. Trotter and Gleser's (1952) sample was largely healthy soldiers in their teens and twenties, while the present sample had a mean age of 59 years.

Hooten was one of the first to observe that stature decreases with age, primarily due to the loss of intervertebral soft tissue (cf. Trotter and Gleser 1951). Osakabe et al. (2001) reported that degeneration related to age affects the entire spinal unit, including bone mass, tissue densities and fluid levels. Similarly, Pollintine et al. (2004) found that aging reduces the height of the intervertebral discs, hence shortening the length of the spinal column.

Statistical tests conducted on the present sample (n = 233) supported this general observation, particularly for men. Older men tended to have less soft tissue than younger men. This would indicate less postmortem expansion in the elderly because they have less soft tissue to expand. A very similar relationship was found between vertebral pathology and STF in men. The greater the number of fused vertebrae a man had, the less soft tissue he had between his vertebrae to undergo expansion. It is interesting that a significant correlation between age, vertebral pathology and STF was indicated only in the men. This may be due to the differences in the sample sizes of the men (n = 148) and the women (n = 85) in this study.

There exists one final concern about the age of the Trotter and Gleser (1952) sample. With the inclusion of so many soldiers in their teens, there is always the possibility that they may not have realized their full stature potential at the time of induction and measurement, and may have experienced further stature growth in the years prior to their death. This could have resulted in a portion of the increase noted by

Trotter and Gleser between the recorded antemortem statures of their sample and the estimated postmortem statures.

Stature

It was assumed that inherent stature differences existed between Trotter and Gleser's 1952 sample and the present sample, primarily due to the large number of women and older individuals in the present sample. Therefore, the relationship between STF and stature was explored. As expected, a positive correlation was found between the two traits. Taller individuals tended to have more soft tissue than shorter ones.

Sex and Ancestry

The sample used by Trotter and Gleser (1952) was American White and male. The present sample includes women and American Blacks. Therefore, it was important to confirm that no significant differences were found between soft tissue and either sex or ancestry. The STF of American Black males was similar to that of the American White males in this sample. Similarly, no significant differences in STF were found between men and women. This latter finding was somewhat surprising considering the fact that men, as a group, are generally taller than women (Guegan et al. 2000) and considering the significant positive correlation that existed between stature and STF in this sample. The mean stature of men in this sample was 175.54 cm, with a mean STF of 12.39 cm. The corresponding means for women in this sample were 161.25 cm and 12.02 cm, respectively. Thus, centimeter for centimeter, the women in this sample have a relatively greater amount of soft tissue than the men. This finding was unexpected and may have important implications for future research. For example, if women have a relatively greater component of soft tissue than men, might it be possible that their spines may age slower and be less susceptible to spinal injuries and degenerative disorders than the spines of men? Might this indicate that men and women need different age adjustment factors for stature estimation? What implications may this difference in soft tissue have from an evolutionary aspect, such as in childbearing and longevity?

To Use or Lose? The 2.5 cm Cadaver Adjustment Factor

Due to the differences in age, pathology, and stature between the two samples, and the significant correlation between these three traits and STF, the cadaver adjustment factor of 2.5 cm recommended by Trotter and Gleser is not deemed appropriate for use on the present sample. Because the present sample is much older, and presumably shorter and more pathological than Trotter and Gleser's (1952) sample, it is posited that the 2.5 cm adjustment factor is too robust. However, this does not necessarily mean that no adjustment factor is needed to convert cadaver stature to living stature in this sample.

Rigor mortis has been mentioned (Hauser et al. 2005) as a possible factor influencing cadaver stature. Rigor mortis sets in within several hours after death and can last up to 96 hours. It leads to shortening and stiffening of the muscles, which may affect the maximum extension of the body and the measurement of cadaver stature. Unfortunately, there are no known studies that focus specifically on the postmortem period and cadaver stature fluctuations.

Terry (1940) mentioned obstacles that make the measurement of the dead much more challenging than that of the living such as lack of muscle tone, loss of proper posture and spinal curvature, rigidity, and dehydration. He attributed the discrepancy between living and cadaver stature to be a result of the compression of the intervertebral discs when standing, and their relaxation and subsequent expansion when supine.

Montbeillard was the first to report diurnal differences in stature dimensions (c.f. Redfield and Meredith 1938). In 1776, while conducting a longitudinal study on his seventeen year old son, he reported, "stature tends to decrease during the day and during prolonged exertion, and this loss is regained with rest" (p.293). Bachman's study followed 200 men throughout the course of the day (c.f. Redfield and Meredith 1938). He noted a steady decrease in stature throughout the day: there was a 0.76 cm decrease one hour after rising from bed, and a 2.36 cm decrease by evening. Althoff et al. (1992) and van Deursen et al. (2005) agreed that a greater amount of spinal shrinkage occurs while standing (as opposed to sitting) (c.f. van Deusen et al. 2005). Tyrrel et al. (1985) noted that it is the visco-elastic properties of intervertebral discs that makes them so responsive to periods of loading and relaxation. Adams and Dolan (1995) specified the radial bulging of the fibrous tissue and subsequent fluid expulsion as the causative factors of spinal shrinkage (c.f. Rodacki et al. 2005). Not surprisingly, loading was found to be greatest on the spines of obese individuals and a greater recovery period was necessary for the obese to recover their intervertebral disc height (Rodacki et al. 2005). Perhaps of greatest significance for the present study were the findings of McGill and Axler (1996). Using 32 hours as a benchmark, they noted no further increase in spinal height recovery after an average 8-hour night's rest. This finding might imply that bedridden individuals experience less postmortem expansion than those who die during the course of their daily activities. This finding also might imply that if all living stature measurements were obtained in the supine position, before or immediately after rising in the morning, the optimal stature of an individual would be captured, eliminating the need to make postmortem conversions. However, this type of uniformity would be very impractical for use in the real world.

It is clear that some type of soft tissue adjustment factor is probably necessary to convert cadaver stature to living stature. Because of the great number of factors that affect the differences between antemortem and postmortem stature such as age, pathology, STF, body mass, amount of vertebral loading and unloading time, it is not feasible to determine a suitable adjustment for the conversion of cadaver stature to living stature in the present sample. Therefore, all comparisons among stature estimation methods in this study were made using unadjusted cadaver stature.

Comparison of the Four Stature Estimation Methods

The mean unadjusted cadaver stature of the present sample (170.32 cm) was compared with the mean living stature estimates calculated by each of the four stature estimation methods examined in this study. The table of descriptive statistics (Table 5) revealed much more information about the four stature estimation methods than the stature estimates themselves. The overall range measured by each method was provided, along with the associated minimum and maximum values. The overall range of both anatomical methods was nearly identical to the range of the target variable (cadaver stature). However, both their minimum and maximum range values, while still nearly identical to each other, were shifted higher than the target variable. Conversely, the mathematical method of Totter and Gleser (1952, 1958) exhibited the smallest overall range and standard deviation of all the methods. Its minimum range was nearly identical to the anatomical methods, but its maximum range was much lower. This may explain why the mean stature estimate provided by this method was the furthest from the target variable mean. FORDISC 3 had a relatively small overall range, displayed the highest minimum range of all the methods, and had a maximum range that was closest to the maximum range of the estimated variable (cadaver stature). This might explain why, despite its small range, it was the only method to overestimate the target variable. It also provided the closest estimate to the target variable mean.

Additional information about the performance of the four methods was gleaned from the results of the linear regression scatter plots (Figures 2, 3, 4 and 5). Not surprisingly, the highest R-square values were attributed to the anatomical methods. This is because these methods based their stature estimates on a much greater number of skeletal elements than the mathematical methods.

Additional statistical tests elucidated patterns or trends in the way each method estimated stature. All four methods were prompted to provide stature estimates for the shortest and tallest sub-samples. While the estimates provided by all four methods were significantly different from the target means on a statistical level, there were some consistent patterns. The methods of Trotter and Gleser, Fully-1956 and Fully-2006 formed a relatively tight cluster in their stature estimation of the short sub-sample; they all overestimated stature by a relatively similar amount (approximately 3.0 cm). FORDISC 3 was much further away, with an overestimate of 5.36 cm. There was a similar pattern in the estimation of the tall sub-sample. This time, FORDISC 3, Fully-2006 and Fully-1956 formed a tight trio in their estimates; all underestimated target stature by approximately 3.50 cm. The method of Trotter and Gleser was not even close to the others, with an underestimate of 7.51 cm. Thus, while FORDISC 3 assumed relative "outlier status" in estimating the short sub-sample, Trotter and Gleser did so in estimating the tall sub-sample, and by a much greater amount.

Duyar et al. (2006) explained that because regression equations are based upon the mean stature of a target population, they tend to work best in estimating the heights of average individuals. This means that the statures of the very tall tend to be underestimated, and statures of the very short tend to be overestimated. If this is indeed the case, the "average individuals" that Trotter and Gleser estimated best were in the shortest 10% of the present sample. This hints at some degree of secular change in stature between this study's modern sample and Trotter and Gleser's historic sample. Similarly, FORDISC 3 was best at estimating the tallest individuals, which may indicate that this program draws from a relatively tall modern sample.

Dupertuis and Hadden (1951, p.15) expressed their dissatisfaction with stature regression equations they deemed to be obsolete when they wrote, "For many years the need for the revision of the formulae for estimating stature from long bone lengths has been apparent. The same formulae have been in use for the last half century, formula developed by Pearson in 1899 from data gathered by Rollet in 1889". Almost fifty years later, we heard a similar plea from Meadows and Jantz when they expressed concern about the continued applicability of the long-popular Trotter and Gleser regression equations (1952, 1958), "Ideally, what is required is up-to-date stature estimation formulae derived from the contemporary population from which modern forensic cases are drawn" (1995, p.766). They assert that the 19th century population, from which Trotter and Gleser obtained the data for their equations, was born at the point in U.S. history when average stature was at an all-time low. The study conducted by Meadows and Jantz indicated that a secular change in height in the American population was accompanied by a significant change in limb proportions, thus the need for new equations (1995).

It must be noted that it is impossible to assess how representative the Bass and Maxwell samples are of the current general population, despite their modernity. Many individuals who find a final resting place in collections are unclaimed, homeless and/or donated for financial reasons, while others are passed to the repositories from local medical examiners. Komar (2008) specified that only 17% of the Maxwell population was self-donated. Wilson et al. (2007) found that self-donors in the Bass Collection had higher education levels and were of higher socio-economic status than those who arrived in the collection via other routes (c.f. Komar 2008). Socio-economic status has an influential effect on stature; children that grow up under favorable socio-economic conditions tend to be taller than their less well-off counterparts (Bogin 1988, Malina and Bouchard 2004). However, even though a person may die under meager circumstances does not necessarily mean they were raised under such conditions, and vice versa. Thus, it is impossible to know to what extent these individuals may have been impeded from obtaining their maximum stature (if at all) and how representative as a group they are of the general population.

Some final information was gained from the estimates provided by the four methods for the sub-sample of individuals with an extra vertebra (n = 24 or 10.3 % of the sample). If this number approximates the distribution of this trait in the general population, it is important to consider how the presence of extraneous skeletal elements may affect stature estimation. Fully-2006, FORDISC 3 and Fully-1956 were fairly close in their stature estimates of this sub-sample. They all underestimated stature by approximately 1.0 cm, while Trotter and Gleser underestimated stature by 4.58 cm.

Lundy (1988) examined a case involving the sacralization of the sixth lumbar vertebra. He estimated the individual's stature using both the 1956 Fully method and Trotter and Gleser's regression formula. The Fully method exactly duplicated the individual's military-documented living stature, while the regression equation of Trotter and Gleser underestimated stature by 2.54 cm. When the Trotter and Gleser equation was calculated a second time, with the addition of the height of the sixth lumbar vertebra, the estimate was right on target. The large underestimation of Trotter and Gleser's method is not surprising. Unlike the anatomical methods, it is based on regression formulae; therefore, it is not designed to be sensitive to particular anomalies such as extra vertebrae. However, why did FORDISC 3, which is also a regression-based method, estimate the stature of this sub-sample so well? A clue may be provided by the way in which it estimated the tall sub-sample in this study. Perhaps the reference population upon which their program is based is relatively tall. Table 5 does indicate that FORDISC 3 has the highest minimum range of all the methods. Hence, FORDISC 3 might tend to estimate stature on the "tall side".

Summary of the Methods

Statistically significant differences were noted in many of the tests that were performed comparing the four methods of stature estimation. However, for all practical purposes, these methods estimated stature in fairly close proximity to each other. When applied in a forensic and/or archaeological assessment, a stature range is normally employed, which encapsulates one to two standard deviations from the mean measurement (Trotter and Gleser 1952). Therefore, the use of a range drastically diminishes the importance of small statistical differences. It was demonstrated in this study that each method displays particular tendencies in the way it estimates stature. It is suggested that one keep these tendencies in mind when utilizing a particular method and applying the appropriate range. A short summary of each method follows.

Fully-1956 and Fully-2006

The anatomical method of Fully is thought by many to be more reliable because it provides a personalized stature estimate (Formicola 1993, Ousley 1995). The only source of error comes from the calculation of the soft tissue factor and the degree of curvature of the spine (Formicola 1993). Sex, heredity, limb proportions, sexual dimorphism, and stature extremes are already accounted for. Perhaps Ousley (1995, p.772) verbalizes it most succinctly, "…the best possible estimate of biological stature from the skeleton would be the Fully method or a variation thereof, since it incorporates all skeletal components of stature". On the other hand, a relatively complete skeleton is needed to utilize this method, which is often difficult to obtain in forensic and archaeological contexts. This method also requires more time and practice to master. It should be noted that no associated range is provided with this method; one must calculate his/her own range when reporting the estimated stature.

The majority of researchers that have employed the Fully method in their research did so as a standard by which to measure the accuracy of other methods, especially in ancient groups where living stature was unknown (Formicola 1993, Bidmos 2005, Petersen 2005). Alternatively, others have employed the Fully method as a tool to develop regression equations for specific populations such as ancient Egyptians (Raxter et al. 2008), Early Holocene skeletons (Formicola and Giannecchini 1999) and prehistoric Native Americans (Sciulli et al. 1990).

Based on the overall results with the present sample, both of the Fully methods performed very consistently with each other, within 0.5 cm or less of each other on all tests. They had similar overall ranges, both with each other and with the target variable (cadaver stature). They had the highest R-square values, and were always part of the group "cluster" when measuring extreme groups: short, tall and extravertebral. In summary, both of these anatomical methods demonstrated an ability to estimate stature reliably and consistently on the present sample.

Because of their proximity to each other in estimating stature, it was difficult to determine which was "best". When the new Fully-2006 equations were developed, the authors utilized Trotter and Gleser's 2.5 cm adjustment factor to convert cadaver stature to living stature in their sample (Raxter et al. 2006). Their sample, from the Terry Collection, was quite similar to the present sample in demographic composition. Thus, there was some concern that the cadaver adjustment factor may not have been appropriate for their sample. Perhaps the subsequent age corrections the authors applied negated any deleterious effects of the adjustment factor.

Trotter and Gleser (1952, 1958)

The mathematical method of Trotter and Gleser (1952) estimates stature based upon regression. The femur was chosen for use in this study because it was found to have the highest and most reliable correlation with stature (Totter and Gleser 1958, Meadows and Jantz 1995).

Due to differences in limb proportions, genetics, sex, and secular changes among groups, the regression equation one uses must be population-specific and sex-specific to the individual whose height is being estimated (Stevenson 1929). The population from which Trotter and Gleser (1952) devised their regression equations was a very large sample of World War II and Korean War soldiers, as well as a group from the historic Terry Collection. The performance of their regression equations on the present modern sample seemed to indicate that some degree of secular change in stature and/or limb proportions has occurred since last century. While their equations performed adequately on the short and average-statured individuals of this sample, they performed poorly on the taller individuals and those with extra vertebrae.

There is one other issue that needs to be addressed in regards to the use of Trotter and Gleser's (1952) regression equations. The age adjustment formula that they recommended for individuals over the age of thirty was applied in the present study. However, other researchers indicate that this formula may not be adequate. Galloway et al. (1988) studied age-related changes in stature and their relationship to changes in bone mineral density (BMD) in modern Arizona Whites, primarily women. In general, no significant changes in stature were noted until the age of 45. They found stature loss (and the rate at which it is lost) to be highly correlated with low BMD values. Significant declines in BMD can lead to vertebral collapse or wedging and a change in posture and/or loss in stature. Like Trotter and Gleser (1952), the authors note a sharp loss of stature in women over eighty. No significant trends were noted among men. Based on their findings, the authors suggested a new age correction factor that should be employed in the estimation of stature in individuals over the age of 45 (.09% x maximum height) x (age – 45).

Giles (1991) views both of these age adjustment equations as inadequate. He claims that Galloway's formula overestimates stature loss, while Trotter and Gleser's model begins too early in life and is not robust enough for the latest years. He published an age adjustment table, which allows an anthropologist to simply look up the appropriate adjustment for a particular age or age range. This number is then subtracted from the estimated stature. Giles obtained the data for his table from Borkan et al. (1983) (male data) and Cline et al. (1989) (female data); the data are part of two on-going, long-term, longitudinal stature studies involving living subjects.

Therefore, if Trotter and Gleser's (1952) regression equations continue to be used, it is imperative that the most optimal age adjustment formula be determined. The scope of the present study precluded the investigation of this matter, but it is an important question that should be addressed in future research.

Finally, the method of Trotter and Gleser (1952) has enjoyed popularity because of its simplicity and ease of use. Only one long bone is necessary, and it only takes about ten minutes to measure it, insert the measurement in the appropriate equation, and add the desired standard deviation to obtain the target stature range (one standard deviation is provided, but can be doubled for greater reliability). As a result of this study, it is highly recommended that the two-standard deviation range be employed. Also, caution is recommended when using these equations to estimate the stature of taller individuals.

FORDISC 3 (Jantz and Ousley 2005)

FORDISC 3 is a windows-based computer software program that estimates stature using linear regression "on the fly" (Jantz and Ousley 2005). This means that the estimate given depends upon the number and type of skeletal elements used in the calculation. The more skeletal measurements that are entered into the program, the more accurate the stature estimation. In this study, only three long bone measurements were used; therefore, the program was not given a chance to perform at its optimal potential. The calculations that FORDISC 3 makes are based on a large data base of modern skeletal individuals derived from modern forensic cases in North America (approximately 400 individuals). There are no known previous studies that examine the use of FORDISC 3 in stature estimation.

FORDISC 3 (2005) uses living (forensic stature) as a primary source document: drivers' licenses, police records, medical records, etc. Thus, there is no perceived need to account for, nor adjust for the effects of age. However, the reliability of forensic statures has been frequently questioned. Snow and Williams (1971) were some of the first to discuss the pitfalls of using forensic statures. They clearly demonstrated how sloppy measurement practices and varying protocol among different agencies can result in widely varying recorded statures for the same individual. Postural slump and the addition of footwear can also lead to significantly different measurements of stature.

Drivers' licenses are considered to be the most common source of forensic stature (Willey and Falsetti 1991). However, the licensing bureau normally allows the driver to self-report their stature and weight. This can lead to inaccuracy due to ignorance and/or deception. Older people tend to overestimate their height, often reporting their stature as they remember it in earlier years (Ousley 1995). Men tend to round off to the nearest even number and in general, tend to overstate their height more than women (Willey and Falsetti 1991). Short people tend to overestimate their stature and tall people tend to underestimate it, both groups attempting to fall into more socially-acceptable ranges. The most accurate forensic stature measurements appear to be those taken from official records such as military induction documents, physicals by qualified medical personnel and hospital records (Snow and Williams 1971).

While the overall range and R-square values of FORDISC 3 (2005) in this study were similar to that of Trotter and Gleser, FORDISC 3 appeared to estimate stature at the opposite end of the spectrum from them. While Trotter and Gleser experienced trouble reaching the tallest portion of the sample, FORDISC 3 experienced some difficulty in estimating the short sub-sample. Also, FORDISC 3 was the only method to overestimate the mean cadaver stature of the sample. This could indicate that the forensic population upon which it is based is a significantly taller and/or youthful sample than the study sample. This may also be the reason FORDISC 3 performed so well in estimating people with extra vertebrae. It is also possible that the absence of an age correction mechanism is being reflected.

The results of this study indicate that FORDISC 3 (2005) has the potential to be a useful tool in the estimation of stature, if used correctly. With only 400 individuals in its forensic stature database, it is still in the infancy stage. One must keep in mind that this method is dependent on the number and type of skeletal measurements that are entered. While it did exhibit some difficulty estimating the stature of shorter individuals, the method did provide an accompanying range to buffer the stature estimate it provided. It is highly recommended that a two standard deviation range be applied.

CHAPTER V

CONCLUSION

The primary goal of this study was to compare four different stature estimation methods to determine which is the most accurate in estimating living (forensic) stature in modern populations. Additionally, the 2.5 cm cadaver stature adjustment factor of Trotter and Gleser (1952) was evaluated for use in the present sample.

Because of the inherent differences (sex, age, stature, and pathology) between the present sample and Trotter and Gleser's 1952 sample, and the positive correlations between these differences and intervertebral soft tissue, it was concluded that the 2.5 cm adjustment factor was not appropriate (too robust) for the present sample. Thus, a comparison of the four stature estimation methods was conducted without converting the cadaver statures of the sample to living statures.

In the present study, the anatomical methods of Fully (1956) and Raxter et al. (2006) demonstrated greater accuracy, dependability and sensitivity than their mathematical counterparts (Trotter and Gleser (1952, 1958) and FORDISC 3 (Jantz and Ousley 2005)). When estimating stature, the anatomical methods employ all of the skeletal elements that contribute to height; therefore, the resulting stature estimate correlates closer with skeletal height than do the other methods, which are strictly based on long bones. Since the anatomical method utilizes all stature-contributing skeletal elements, it essentially personalizes the stature estimate of each individual; the other methods compare each individual to a population mean. This could potentially make a difference in forensic and/or archaeological cases if the individual in question is abnormally tall or short, has extra vertebrae, has congenital limb anomalies, or is of unknown sex and/or ancestry. While it is often said that the use of the anatomical method is more tedious and time-consuming, this is only true for those unfamiliar with it. If enough skeletal elements are present, it should be routinely employed.

The stature equations of Trotter and Gleser consistently tend to underestimate stature. This could be due to secular change that has occurred since their derivation in 1952 and 1958 (Meadows and Jantz 1995). If the regression equations of Trotter and Gleser are continued to be used for the prediction of stature in modern forensic cases, they should be used with caution, and the final stature estimate should be buffered by two standard deviations. The use of the age correction factor recommended by the authors (Trotter and Gleser 1952) for individuals over 30 years of age is also questionable for use with modern groups.

Conversely, FORDISC 3 (Jantz and Ousley 2005) tends to systematically overestimate stature. This may be due to the tallness of the forensic sample upon which it is based, or because FORDISC 3 does not correct for age. It may also be because a deficient number of skeletal elements were used in its calculation (only three were used in this study). It is recommended that as many skeletal elements as possible be utilized when using this program, and that a range buffered by two standard deviations be employed.

APPENDIX A

DATA RECORDING SHEET

Identifying Data

Sex-

Age-

Ancestry-

Stature-

Source of Stature-

Skeletal Measurements (mm)

Cranium-

C2-

C3-

C4-

C5-

C6-

C7-

T1-

T2-

T3-

T4-

T5-

T6-

T7-

T8-

T9-

T10-

T11-

T12-

L1-

L2-

L3-

L4-

L5-

S1-

	left	**right**
Femur (max length)		
Femur (phys length)		
Tibia		
Calcaneus/Talus		

NOTES:

APPENDIX B

MEASUREMENTS

The Measurement Procedure

Each set of skeletal remains was subject to 33 measurements. “Revision of the Fully Technique for Estimating Statures” by Raxter et al. (2006) served as the basis for the measuring techniques employed to maintain consistency throughout the entire sample. All measurements were rounded to the nearest whole millimeter.

Cranial Height

The maximum height of the cranium is the distance from the bregma to the basion. Bregma is defined as the juncture of the coronal and sagittal sutures at the top of the skull. Basion is the point on the base of the skull, on the mid-sagittal anterior edge of the rim, just between the occipital condyles. In preparation for measurement, each cranium was placed on its right side, upon a small cloth sandbag for stability. Each cranium was measured from the left side, using a set of spreading calipers. Because bregma is a more stable location than basion, one end of the caliper was secured at bregma before placing the other end at basion.

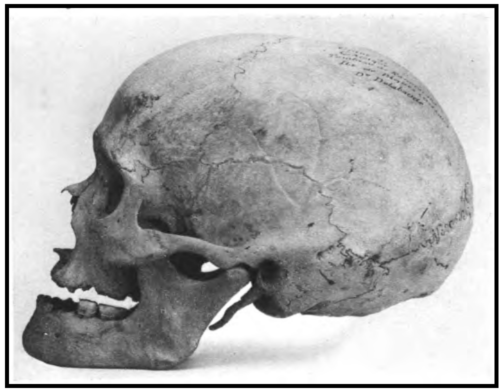


Figure 1: Cranial Height

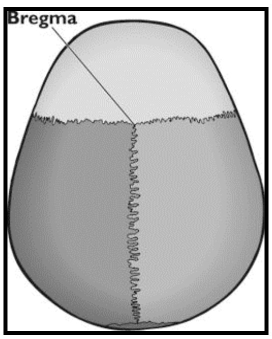


Figure 2: Bregma

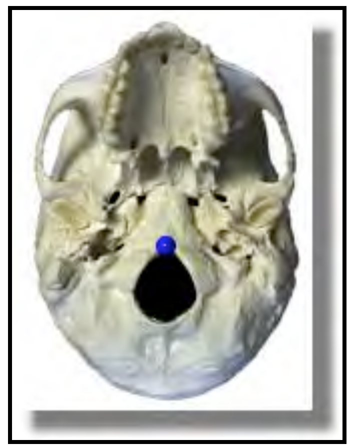


Figure 3: Basion

Many crania were in two sections, having had autopsy surgery. This presented very little issue, as the pieces normally fit back together very well. In the few cases where more stability was needed, a few pieces of scotch tape were used to temporarily secure the cranium until an accurate measurement could be procured. While a few millimeters are normally lost in the autopsy cut, the crania could usually be placed back together in a natural position. All individuals with autopsy cuts were noted, as well as any problems associated with them.

More problematic were ambiguous and/or obliterated bregmas. In most cases, it was the sagittal suture (not the coronal) that was faded and/or totally obscured.

Normally, a very faint line remained, allowing the original path of the suture to be traced. In several instances, there were two bregma points or perhaps a wormian bone where the bregma should be. In these cases, an approximation had to be made concerning where the natural bregma would have been positioned if the wormian bone and/or additional suture lines had not been present. In all cases, an annotation was made on the individual's recording sheet about the issue, and in many cases a simple diagram was sketched to detail the position of the bregma(s) and how the final measurement was made.

Several individuals exhibited some degree of perimortem or postmortem trauma to the cranium. Perimortem damage, such as that caused by gunshot wounds, vehicular impact and/or blunt force trauma was more problematic because the sections of bone did not usually fit back together properly, leaving gaps. If the damage was too extensive to obtain a valid measurement, the individual was not included in the study. If the damage was minimal and the specimen was chosen for inclusion in the study, the degree and type of damage was noted.

Figure 4: Autopsy Cut

Figure 5: Wormian Bone

Vertebrae

All vertebrae were measured for their maximum height, using a set of sliding digital calipers (Mitutoyo absolute digimatic). The digital calipers are greatly preferred over the manual style for two primary reasons: the measurement is visually displayed, which alerts the researcher when he/she has approached the largest and/or most appropriate section of vertebra for measurement, eliminating guesswork and subjective assessments. The calipers were calibrated to zero each time they were turned from the "off" to the "on" position.

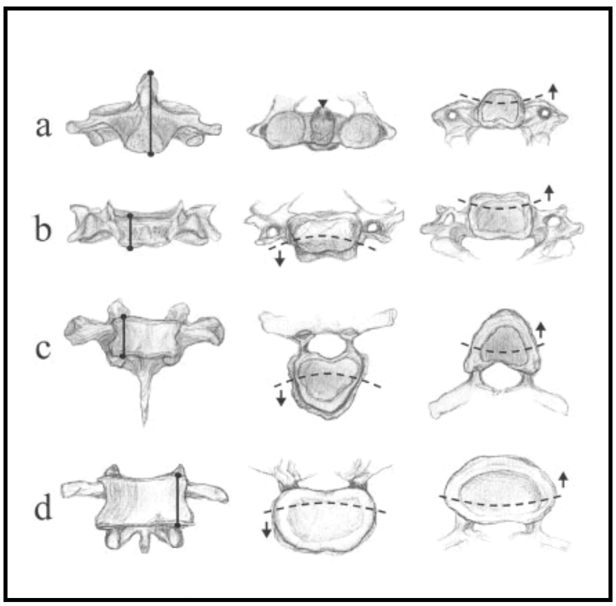


Figure 6: Maximum Height (Vertebrae) (Raxter et al. 2006)

Every effort was made to maintain the calipers in a position perpendicular to that of the centrum being measured. All vertebrae were measured in anatomical position (superior end up) unless mentioned otherwise. Measurements of pathological growths and processes were excluded to the greatest extent possible. The first cervical vertebra, or atlas, is not measured when employing the Fully method (1956), because the second cervical vertebra (C2), or axis, overlaps the atlas.

The maximum height of each axis was obtained by measuring from the tip of the dens to the most inferior point on the rim of the centrum. If the tip of the dens was accompanied by obvious pathological bone growth, the measurement did not include it. In several cases, it was necessary to turn the vertebra around and measure it from the posterior side so that the line of demarcation between the tip of the dens and the pathological growth was discernible.

For the remainder of the cervical vertebrae (three through seven), the maximum height was obtained from the anterior one-third of the centrum. This prevented the inclusion of any swelling and/or curvature from the sides.

Of all the vertebrae, the third through sixth cervicals were the most difficult to measure because of their ambiguous shapes and sloping angles, especially due to their high incidence of lipping, macroporosity and compression. However, every effort was made to measure them in a consistent fashion from one individual to the next. The maximum height of the thoracic and lumbar vertebrae was taken anywhere along the rim of the centrum, as long as it did not include any swelling from the rib facets and pedicles. While the average individual possesses seven cervical, 12 thoracic and five lumbar vertebrae, (cf. Ortner 2003) there are numerous individuals in this sample with an additional vertebra. In most cases, this manifested as either a thirteenth thoracic or a sixth lumbar vertebra. In all cases, the extra vertebra was measured, noted and included in the individual’s skeletal height.

Similarly, several individuals in the sample were missing a vertebra. While this is sometimes a congenital occurrence, other specimens are missing due to loss, damage or field experimentation. One can usually ascertain which vertebra is missing (in non-congenital instances) on the basis of size and articulation. In this study, individuals with one missing vertebra were included. If the loss was determined to be non-congenital, the measurement of the missing vertebra was estimated by averaging the heights of its superior and inferior neighbors. All such instances are clearly noted in the individuals' records. An exception to this rule is those individuals missing a C2, C3 or L5; these vertebrae cannot be estimated by averaging because of an absent or non-similar adjacent vertebra. Thus, individuals missing those particular elements were not included in the sample. Similarly, individuals missing more than one vertebra were not included in the sample.

The general pathological state of each section of vertebrae was annotated, as well as the extent to which the pathology interfered with obtaining measurements. The most common forms of vertebral pathology were lipping, osteophytes, macroporosity, compression, Schmorl's nodes and their associated collapse, curving of the spine due to osteoporosis, and the destructive result of Diffuse Idiopathic Skeletal Hyperostosis or D.I.S.H. Every effort was made to avoid measuring lipped and osteophytic bone that projected above and below the natural limits of the centrum. Schmorl's nodes posed an issue only if they were so large as to cause complete vertebral collapse, which normally occurred at the midpoint of the centrum before expanding to the surrounding areas. In these cases, measurements were obtained as close as possible to the pedicles/facets without permitting the inclusion of any of their associated swelling. D.I.S.H. is a form of degenerative arthritis, in which the ligaments running parallel to the spinal column turn to bone (cf. Ortner 2003). It is often called "flowing calcification" because these ossified ligaments resemble hardened candle wax dripping down the affected vertebrae. In reality, the ossified tendons form continuous osteophytes which conjoin several vertebrae together. In most instances in this sample, there was still enough space remaining between vertebrae to obtain individual vertebral measurements because the disease usually affected only one side of the vertebral column. In cases of complete fusion, the vertebrae were measured as a single unit. Similarly, perimortem and postmortem damage was noted. Most of the damage to the vertebrae of the individuals in this study is of the postmortem variety. If the damage was expected to interfere with accurate measurements, the individual was excluded from entry into the study sample.

Figure 7: D.I.S.H.

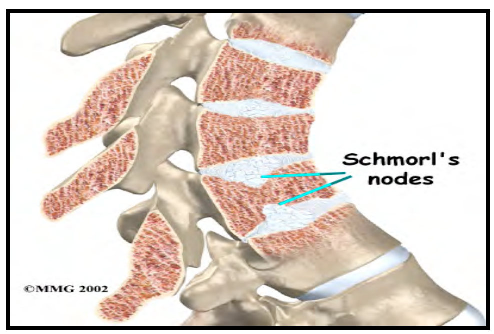


Figure 8: Schmorl's Nodes

First Sacral Vertebra (S1)

The first sacral vertebra was measured using digital calipers from the highest point of the sacral promontory to the suture (line of fusion) between the first and second sacral vertebrae (S1 and S2). In older individuals, this line is often ambiguous and/or totally obliterated, so care must to be taken to measure the correct location. Normally, the line of fusion is expected to bisect the first set of sacral foramina. Because of the advanced age of this sample, it was not uncommon for the sacrum to be fused to one or both innominates, but this posed absolutely no problem from a measurement standpoint. However, the fusion of a fifth lumbar vertebra (L5) to the sacrum occasionally did pose an issue. If the advanced degree of fusion made it difficult to delineate even a faint line between the L5 and the sacral promontory, the two elements were measured as one unit. The most problematic aspect of measuring the S1 was in differentiating a fused L6 from an S1. A sixth lumbar that was separate from the sacrum or in the early stages of fusion to the sacrum was easy to identify. However, if an L6 was largely fused to the sacrum, the potential existed to mistake it for an S1, unintentionally docking the individual approximately two inches in skeletal height.

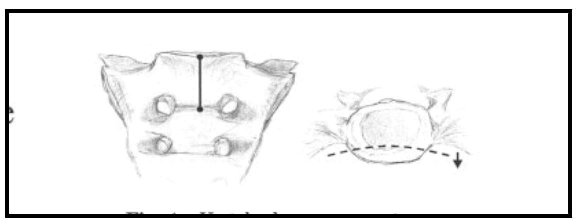


Figure 9: **Maximum Height (S1)**
(Raxter et al. 2006)

<u>*Femur*</u>

Two measurements were taken on each femur using an osteometric board: the maximum length and the bicondylar length (or physiological length). The bicondylar length is necessary for calculation of the Fully methods (1956, 2006), and the maximum length is needed for Trotter and Gleser's stature regression formulas (1952, 1958) and FORDISC 3 (Jantz and Ousley 2005). Both femora of each individual were measured unless it was impossible due to absence, damage and/or severe pathology. Two different types of osteometric boards were employed because I was limited to what was available at each collection location. The 42 Maxwell individuals were measured with a metal

Paleo-Tech portable osteometric board. The Bass individuals were measured with the standard wooden tracked variety. However, the same measurement technique was maintained throughout the entire sample.

To measure maximum length, a femur was placed on the platform of the osteometric board, anterior side up, and a measurement was taken from the distal tip of the medial condyle to the most distal aspect of the femoral head. To obtain bicondylar length, a femur was positioned on the osteometric board, anterior side up, and a measurement was taken from both condyles to the most distal aspect of the femoral head.

A general description of pathology was noted in the margin on each individual's recording sheet. The most common pathology noted for the femur was fractures (antemortem, perimortem and postmortem). Of the antemortem variety, many were badly healed, leading to misalignment and increased bone deposition (calus). Perimortem and postmortem fracturing was more problematic. However, fairly strict acceptance rules were maintained throughout the study. If a bone was broken into more than two sections, it was not included. The same rule applied to sections that did not fit back together easily and naturally. Many bones contained rods, screws, pins and/or other hardware.

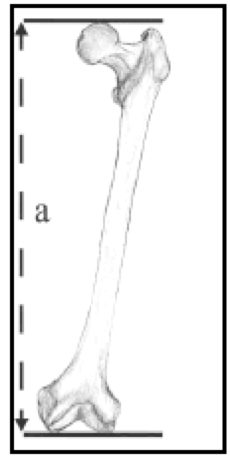


Figure 10: Maximum Length (Femur)

Figure 11: Bicondylar Length (Femur) (Raxter et al. 2006)

Hip replacements were a fairly common phenomenon in this sample, especially considering the advanced age of the majority of the individuals. These surgically-altered bones were measured in the exact same manner as their unaltered counterparts. If a bone was too pathological to obtain an accurate measurement, it was not included in the study. While it is preferable to obtain measurements from the long bones of both sides of each individual, only one bone of each pair is required to calculate any of the stature estimation methods used in this study.

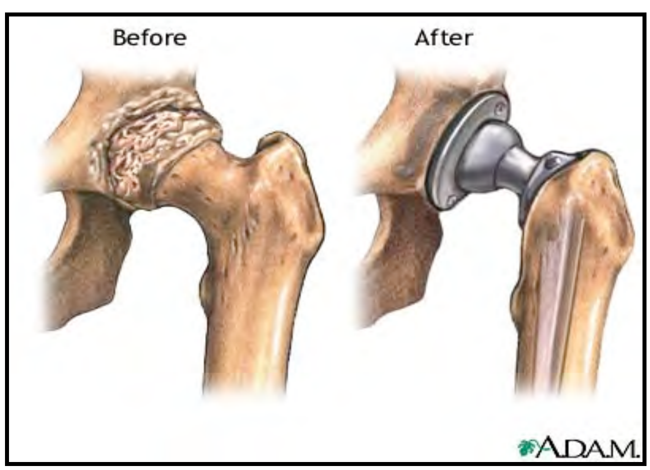


Figure 12: Hip Replacement

Tibia

Using an osteometric board, the maximum length of the tibia was taken from the tip of the medial malleolus at the distal end to the most superior point of the lateral condyle at the proximal end (without the proximal eminence). The distal end was positioned at the stationary end of the osteometric board. The left tibia was measured with the posterior side facing upwards, and the right tibia was measured with its anterior side facing upwards. This difference in positioning permitted the most direct line between the medial malleolus and lateral condyle of each bone without the inclusion of the eminence. Fractures, pathology and knee replacement devices were handled in the same manner as with the femur.

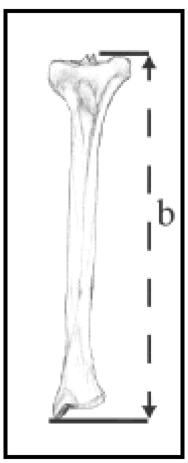


Figure 13: **Maximum Length (Tibia) (Raxter et al. 2006)**

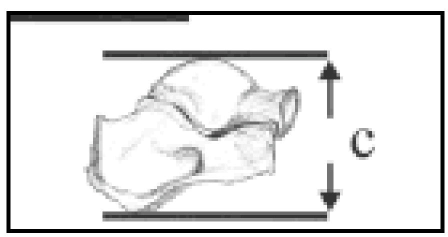


Figure 14: **Maximum Height (Calcaneus/Talus) (Raxter et al. 2006)**

Calcaneus/Talus

Using an osteometric board, the calcaneus and talus were measured in the articulated position. Of all the measurements contributing to the Fully Method (1956), this was the most difficult to position and obtain. With the lateral edge of the articulated pair facing up, the trochlea of the talus was placed up against the stationary end of the board, with both edges of the trochlea in contact with the board. The mobile end of the board was brought up to meet the most inferior point of the calcaneal tuber, which remained in a parallel position in relation to the stable end of the board. While manipulating the moveable end of the board to locate a parallel position, both edges of the trochlea had to stay in contact with the stationary end; the entire unit had to remain articulated as well. This measurement took some coordination, practice and repetition to master.

Aside from its difficulty, this measurement is also open to some degree of observer subjectivity. What appears parallel to one person, may not appear that way to another. Also, if the unit is measured with the medial side upwards (instead of the lateral) it will be very hard to monitor constant contact of the trochlea edges with the board. Of all the Fully measurements, this one has the greatest potential to vary by a few millimeters, even with the same observer. If a bone was too damaged to be measured accurately, it was not included. If one element of an articulated pair was missing, neither could be measured; a complete articulating unit was necessary (talus and calcaneus). However, only one such complete unit was needed per individual.

APPENDIX C

STATISTICAL OUTPUT (SPSS)

Distribution of Data (Cadaver Stature)

Model Name		MOD_1
Series or Sequence	1	Cadstat
Transformation		None
Non-Seasonal Differencing		0
Seasonal Differencing		0
Length of Seasonal Period		No periodicity
Standardization		Not applied
Distribution	Type	Normal
	Location	estimated
	Scale	estimated
Fractional Rank Estimation Method		Blom's
Rank Assigned to Ties		Mean rank of tied values

Estimated Distribution Parameters (Cadaver Stature)

		Cadstat
Normal Distribution	Location	170.3228
	Scale	10.81614

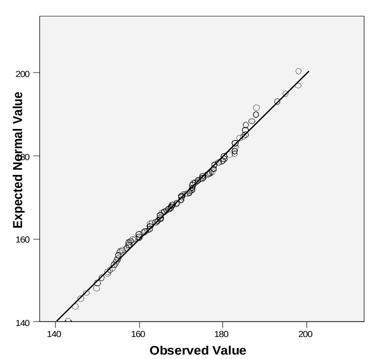


Figure 1: Q-Q Plot (Cadaver Stature)

Age vs. Soft Tissue Factor

Correlations (females)

		Age	STF
Age	Pearson Correlation	1	-.156
	Sig. (2-tailed)		.153
	N	85	85
STF	Pearson Correlation	-.156	1
	Sig. (2-tailed)	.153	
	N	85	85

Correlations (males)

		Age	STF
Age	Pearson Correlation	1	-.209(*)
	Sig. (2-tailed)		**.011**
	N	148	148
STF	Pearson Correlation	-.209(*)	1
	Sig. (2-tailed)	.011	
	N	148	148

* Correlation is significant at the 0.05 level (2-tailed).

Correlations (combined male and female

		Age	STF
Age	Pearson Correlation	1	-.188(**)
	Sig. (2-tailed)		**.004**
	N	233	233
STF	Pearson Correlation	-.188(**)	1
	Sig. (2-tailed)	.004	
	N	233	233

** Correlation is significant at the 0.01 level (2-tailed).

Soft Tissue Factor and Youngest 10%

Descriptive Statistics (STF)

	N	Minimum	Maximum	Mean	Std. Deviation
STF	23	2.01	21.78	14.7909	4.20116

Descriptive Statistics (Age)

	N	Minimum	Maximum	Mean	Std. Deviation
Age	23	23.00	39.00	33.3478	5.05073

Soft Tissue Factor and Oldest 10%

Descriptive Statistics (STF)

	N	Minimum	Maximum	Mean	Std. Deviation
STF	23	1.56	22.21	9.8561	5.26243

Descriptive Statistics (Age)

	N	Minimum	Maximum	Mean	Std. Deviation
Age	23	82.00	96.00	86.6957	4.30047

One-Sample Test (STF of Young vs. Old)

	Test Value = **14.79**					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
STF	-4.496	22	**.000**	-4.93391	-7.2096	-2.6583

Pathology vs. Soft Tissue Factor

Correlations (females)

		STF	Fused verts
STF	Pearson Correlation	1	.051
	Sig. (2-tailed)		.640
	N	85	85
Fused verts	Pearson Correlation	.051	1
	Sig. (2-tailed)	.640	
	N	85	85

Correlations (males)

		STF	Fused verts
STF	Pearson Correlation	1	-.186(*)
	Sig. (2-tailed)		**.023**
	N	148	148
Fused verts	Pearson Correlation	-.186(*)	1
	Sig. (2-tailed)	.023	
	N	148	148

* Correlation is significant at the 0.05 level (2-tailed).

Correlations (combined males and females)

		STF	Fused verts
STF	Pearson Correlation	1	-.108
	Sig. (2-tailed)		.101
	N	233	233
Fused verts	Pearson Correlation	-.108	1
	Sig. (2-tailed)	.101	
	N	233	233

Soft Tissue Factor: Males vs. Females

Group Statistics

		N	Mean	Std. Deviation	Std. Error Mean
STF	M	148	12.3913	4.43064	.36420
	F	85	12.0187	5.71993	.62041

Independent Samples Test (Males vs. Females)

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Upper	Lower
STF	Equal variances assumed	6.641	.011	.554	231	.580	.37258	.67211	-.95167	1.69682
	Equal variances not assumed			.518	142.216	.605	.37258	.71941	-1.04954	1.79470

Soft Tissue Factor and Stature (Entire Sample)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.457(a)	.209	.205	9.64238

a Predictors: (Constant), STF

ANOVA(b)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5664.078	1	5664.078	60.920	.000(a)
	Residual	21477.347	231	92.976		
	Total	27141.425	232			

a Predictors: (Constant), STF
b Dependent Variable: Cadstat

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	158.043	1.695		93.219	.000
	STF	1.002	.128	.457	7.805	.000

a Dependent Variable: Cadstat

Soft Tissue Factor: Tallest 10% and Shortest 10%

Descriptive Statistics (Shortest 10%)

	N	Minimum	Maximum	Mean	Std. Deviation
Cadstat	23	143.00	155.00	151.7670	3.55789
STF	23	-1.99	12.27	7.0783	3.80845

Descriptive Statistics (Tallest 10%)

	N	Minimum	Maximum	Mean	Std. Deviation
Cadstat	23	184.00	198.08	188.2130	4.19239
STF	23	7.14	24.44	15.0752	4.30675

One-Sample Test (STF: Tallest vs. Shortest)

	Test Value = 7.0783					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
STF	8.905	22	.000	7.99692	6.1345	9.8593

Soft Tissue Factor: White Males vs. Black Males

Independent Samples Test (STF: White Males vs. Black Males)

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
STF	Equal variances assumed	1.867	.174	-.121	146	.904	-.12925	1.06890	-2.24177	1.98327
	Equal variances not assumed			-.139	28.437	.891	-.12925	.93097	-2.03495	1.77645

Group Statistics

	Ancestry	N	Mean	Std. Deviation	Std. Error Mean
STF	B	20	12.2795	3.75689	.84007
	W	128	12.4088	4.53962	.40125

Comparison of Methods

Descriptive Statistics (Estimation of Cadaver Stature)

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
CADSTAT	233	55.08	143.00	198.08	170.3228	10.81614	116.989
F-1956	233	54.63	147.73	202.36	168.6085	10.09288	101.866
F-2006 w/age	233	54.80	147.53	202.33	169.0739	9.93260	98.657
T & G	233	42.54	147.25	189.79	167.6533	9.03500	81.631
FORDISC 3	233	46.00	149.50	195.50	170.7730	9.45112	89.324

Descriptive Statistics (Cadaver Stature)

	N	Minimum	Maximum	Mean	Std. Deviation
CADSTAT	233	143.00	198.08	**170.3228**	10.81614

CADSTAT vs. F-1956

One-Sample Test (F-1956 vs. Cadaver Stature)

	Test Value = 170.3228					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
F1956	-2.593	232	**.010**	-1.71435	-3.0171	-.4116

One-Sample Statistics (F-1956)

	N	Mean	Std. Deviation	Std. Error Mean
F1956	233	**168.6085**	10.09288	.66121

CADSTAT vs. F-2006 w/age

One-Sample Test (F-2006 vs. Cadaver Stature)

	Test Value = 170.3228					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
F2006wage	-1.919	232	.056	-1.24885	-2.5309	.0332

One-Sample Statistics (F-2006)

	N	Mean	Std. Deviation	Std. Error Mean
F2006wage	233	**169.0739**	9.93260	.65071

CADSTAT vs. Trotter and Gleser

One-Sample Test (Trotter and Gleser vs. Cadaver Stature)

	Test Value = 170.3228					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
T & G	-4.510	232	**.000**	-2.66950	-3.8357	-1.5033

One-Sample Statistics (Trotter and Gleser)

	N	Mean	Std. Deviation	Std. Error Mean
TandG	233	**167.6533**	9.03500	.59190

CADSTAT vs. FORDISC 3

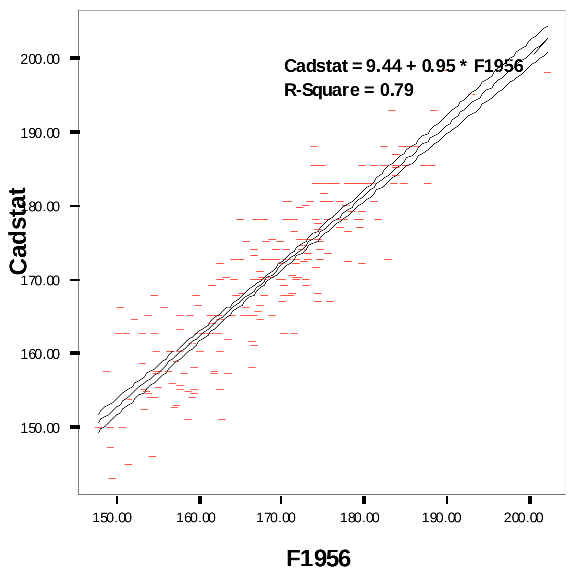
One-Sample Test (CADSTAT vs. FORDISC 3)

	Test Value = 170.3228					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
FORDISC3	.727	232	.468	.45016	-.7697	1.6701

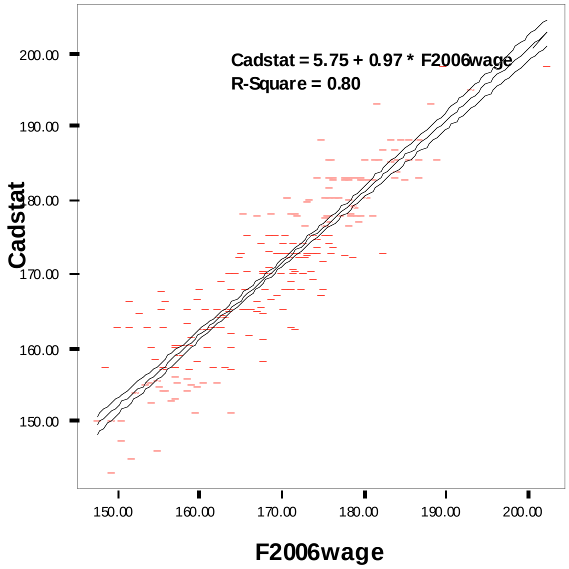
One-Sample Statistics (FORDISC 3)

	N	Mean	Std. Deviation	Std. Error Mean
FORDISC3	233	**170.7730**	9.45112	.61916

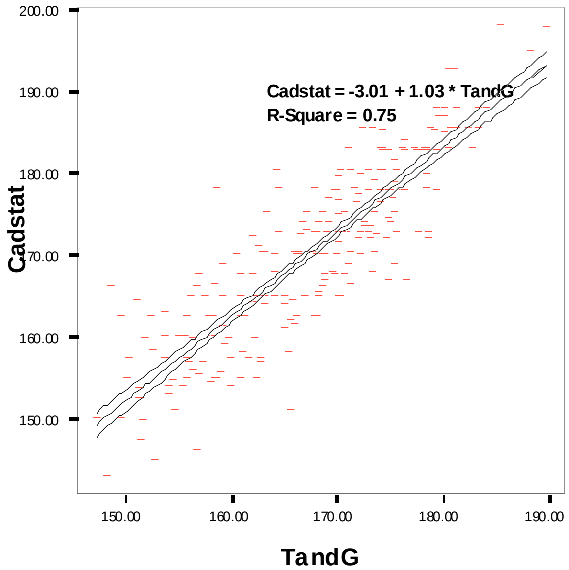
Simple Regression Equations



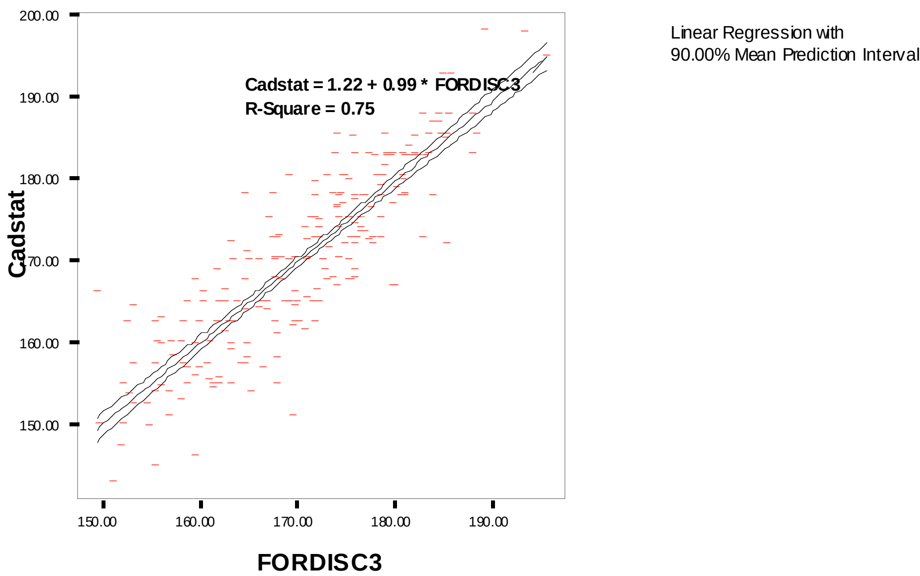
Linear Regression with
90.00% Mean Prediction Interval



Linear Regression with
90.00% Mean Prediction Interval



Linear Regression with
90.00% Mean Prediction Interval



Extravertebral Comparison

Descriptive Statistics (Extravertebral Sub-Sample)

	N	Minimum	Maximum	Mean	Std. Deviation
Cadstat	24	158.00	193.04	**174.9321**	8.59388

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
F1956	24	173.6321	8.20148	1.67412
F2006wage	24	174.0738	8.02262	1.63761
T & G	24	170.3488	7.27116	1.48422
FORDISC3	24	174.0042	7.59499	1.55032

One-Sample Test

	Test Value = 174.93					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
F1956	-.775	23	.446	-1.29792	-4.7611	2.1653
F2006wage	-.523	23	.606	-.85625	-4.2439	2.5314
T & G	-3.087	23	**.005**	-4.58125	-7.6516	-1.5109
FORDISC3	-.597	23	.556	-.92583	-4.1329	2.2813

Short Sub-Sample

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		Mean	Std. Deviation	Std. Error Mean
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
Pair 1	Cadstat - F1956	-2.92217	3.80862	.79415	-4.56915	-1.27520	-3.680	22	**.001**
Pair 2	Cadstat - F2006wage	-3.35435	3.84960	.80270	-5.01904	-1.68965	-4.179	22	**.000**
Pair 3	Cadstat - TandG	-2.72087	4.49501	.93727	-4.66466	-.77708	-2.903	22	**.008**
Pair 4	Cadstat - FORDISC3	-5.35913	4.94165	1.03040	-7.49606	-3.22220	-5.201	22	**.000**

Paired Samples Statistics (Short)

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Cadstat	151.7670	23	3.55789	.74187
	F1956	154.6891	23	4.08429	.85163
Pair 2	Cadstat	151.7670	23	3.55789	.74187
	F2006wage	155.1213	23	4.18402	.87243
Pair 3	Cadstat	151.7670	23	3.55789	.74187
	TandG	154.4878	23	4.46186	.93036
Pair 4	Cadstat	151.7670	23	3.55789	.74187
	FORDISC3	157.1261	23	4.94306	1.03070

Tall Sub-Sample

Paired Samples Test

		Paired Differences						df	Sig. (2-tailed)
					95% Confidence Interval of the Difference			Std. Deviation	Std. Error M
		Mean	Std. Deviation	Std. Error Mean	Upper	Lower	t		
Pair 1	Cadstat - F1956	3.70565	4.54571	.94785	1.73994	5.67136	3.910	22	**.001**
Pair 2	Cadstat - F2006wage	3.63304	4.42346	.92235	1.72020	5.54589	3.939	22	**.001**
Pair 3	Cadstat - TandG	7.51217	3.26190	.68015	6.10162	8.92273	11.045	22	**.000**
Pair 4	Cadstat - FORDISC3	3.49565	3.63986	.75896	1.92166	5.06965	4.606	22	**.000**

Paired Samples Statistics (Tall)

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Cadstat	188.2130	23	4.19239	.87417
	F1956	184.5074	23	6.09806	1.27153
Pair 2	Cadstat	188.2130	23	4.19239	.87417
	F2006wage	184.5800	23	5.85021	1.21985
Pair 3	Cadstat	188.2130	23	4.19239	.87417
	TandG	180.7009	23	4.14640	.86458
Pair 4	Cadstat	188.2130	23	4.19239	.87417
	FORDISC3	184.7174	23	4.70354	.98076

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VITA

Elizabeth Brandt was born and raised in a Philadelphia Suburb, the fourth of five children of an electrician and a school teacher. She graduated in 1980 from Archbishop Wood High School. Although very interested in archaeology at that time, the pursuit of higher learning took a back seat to her thirst for travel and adventure. Twenty-one years in the Army led her around the globe, working in capacities she never dreamed of such as a Russian linguist in Operation Desert Storm, a Blackhawk helicopter team chief in Germany, the branch manager for over 3000 Army linguists in Washington, DC, and the proud mother of an incredible 19 year old daughter.

After retiring from the Army as a master sergeant in 2004, Liz enrolled in the anthropology program at Appalachian State University in Boone, NC. She graduated summa cum laude with a Bachelor of Arts degree in 2006, and continued on to pursue a Masters degree in the forensics track at Texas State University-San Marcos. Liz intends to work as an intern for a period of time before applying to a PHD program, possibly in bioarchaeology.

Permanent Address: lizzz@austin.rr.com

This thesis was typed by Elizabeth T. Brandt.