

A Validation of Stature Regression Equations for Fragmentary Femurs

Lillian Grace Hammer

Department of Anthropology, University of Tennessee, Knoxville

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Dr. Giovanna Vidoli and Dr. Steven Lautzenheiser

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Background

Introduction

The biological profile calculated by forensic anthropologists consists of the stature, sex, population affinity, and age of an individual and is essential to identifying skeletal remains. However, in various forensic contexts, the skeletal elements are fragmentary and incomplete, which makes estimating the biological profile, especially stature estimation, particularly challenging. One common stature estimation method is the anatomical method where each skeletal element that contributes to the stature is measured, and stature is estimated with a mathematical formula. However, when elements of the remains are fragmented, the anatomical method is not possible, and other methods must be implemented to estimate the stature based on fragmentary remains. The other methods currently used are often Steele and Mckern (1969) and the revised version, Simmons et al. (1990). These methods are beneficial in estimating stature; however, they have significant limitations that lead to inaccurate results. The Simmons et al. (1990) method does not account for the variation of human skeletal remains, including differing population affinities.

Population Specific

The population affinity of an individual has a significant impact on the stature of the individual through various environmental and biological factors (Chandran and Kumar 2012). Chandran and Kumar (2012) studied 60 female remains of South Indian population affinity to assess their stature based on fragmentary femurs (Chandran and Kumar 2012). Using regression equations, they determined the appropriate coefficients and correlations that are associated with their specific sample population. Chandran and Kumar (2012) regression equations are essential

for forensic anthropologists, as they are needed to calculate the stature of fragmentary remains associated with this sample population. The regression equations of this study and sample population can be applied to fragmentary remains of South Indian population affinity that are found in a forensic context. Chandran and Kumar (2012) also encourage further research of population affinity specific regression equations in order to be able to calculate stature with fragmentary remains of varying population affinities.

Similarly, further studies have been completed to re-assess the reliability of stature methods such as Steele and McKern (1969). Jacobs (1992) apply the Steele (1970) method to assess the stature of prehistoric Europeans using the femur and tibia stature equations. This sample population is not modern as Steele's population which leads to varying results. For instance, when applying the Steele method to the prehistoric population, the males' heights were calculated higher than they were actually, while females were calculated shorter (Jacob 1992). The calculated height difference emphasizes the importance of revising regression equations to most accurately represent the population affinity. The study deemed that 6 of the 9 femur equations produced inaccurate results after running statistical results such as t-tests (Jacob 1992). The statistics performed show how different and inaccurate the Steele (1970) method is for analyzing this specific population sample and why it is important to re-calculate the coefficients for the specific population affinity that is being measured.

Similarly, Raxter et al. (2008) discusses calculating stature using ancient Egyptian as the sample population and focusing on the lower limbs to assess variation and calculate stature. Previously, attempts were made to use African American data, the anatomical method, and few population samples to calculate proportions (Raxter et al. 2008). The Raxter et al. (2008) study highlights the importance of using a method that uses population specific data, stating that the

population affinity significantly impacts the stature estimation. In this study, the ancient Egyptian remains were compared to that of the United States Terry Collection (Raxter et al. 2008). In difference to Jacob (1992), this study found that when comparing ancient and more historical remains, there was not a significant proportional difference (Raxter et al. 2008). For each population affinity it is crucial to examine and assess if modern formulas or comparative populations are an accurate representation of the historical remains. In addition, Raxter et al. (2008) provides a more accurate formula to be used for the Egyptian remains then were previously used. Despite the similarity to the modern collection of largely differing time period and population affinity, providing a new formula is important to improve the accuracy of calculating stature for this population.

Methods of applying specific population affinities to estimating stature has become a more common practice, with studies analyzing fragmentary remains of specific populations. Included in recent studies is a new suggested femur stature method to be used on the Sri Lanken population (Nanayakkara et al. 2020). Using 96 remains, this study measured multiple landmarks on the femur and created correlation coefficients to determine the accuracy of their developed regression equations (Nanayakkara et al. 2020). These equations included correlation coefficients for each measurement of the femur that can then be applied to fragmentary femurs that are of Sri Lanken population affinity (Nanayakkara et al. 2020). This new formula is important, as it has expanded upon the Steele methods and developed a more applicable formula for specific cases.

Scavenging

Scavenging is a significant threat to the quality of recovered remain and may lead to the inability of using standard stature methods that require complete and intact skeletal remains. This

is a common occurrence as researchers note that the greater trochanter, medial condyle, and lateral condyle of the femurs had scavenging activity in their particular case study (Moraitis and Spiliopoulou 2010). Throughout their case studies, Moraitis and Spiliopoulou (2010) note that the long bones as well as vertebrae and ribs are often affected by scavenging limiting the ability to take measurements for stature.

Another pattern discovered by the Moraitis and Spiliopoulou (2010) study in Greece, is that the scavengers may scatter the long bones in addition to gnawing on bones such as ribs. When scattering does occur by scavengers there is often a loss of skeletal elements rather than fragmentation (Moraitis and Spiliopoulou 2010). Moraitis and Spiliopoulou (2010) report that animals such as foxes may move bones over 3 kilometers away from the original site of remains. Scattering by scavengers can limit the recovery of all the remains and therefore limit the stature calculation capabilities.

Ubelaker and DeGalgia (2020) address how scavenging significantly impacts remains and leads to fragmentation. They studied various cases of scavenging around the United States, with 52% of cases located in the Southern states (Ubelaker and DeGalgia 2020). They concluded that most commonly affected skeletal regions were the thorax and the left leg (Ubelaker and DeGalgia 2020). The types of animals scavenging were diverse, with small and large animals leading to various types of scavenging damage (Ubelaker and DeGalgia 2020). Scavenging damage and fragmentation limits many of the traditionally required measurements for stature. Ubelaker and DeGalgia (2020) concluded that commonly, scavenging occurs at the midsection of the remains and with surface burials. This occurrence indicates that there is a high probability that scavenging will impact essential stature measurements involving the femur.

Collections

Skeletal collections are specialized curated collections made up of human remains to be studied for educational and research purposes. These collections are becoming increasingly popular around the world and research with the collections is found in many notable journal articles, such as *American Journal of Physical Anthropology* and *Journal of Forensic Sciences* (Alves-Cardoso and Campanacho 2022). Alves-Cardoso and Campanacho (2022) analyze the importance and utilization of these collections, how the skeletal collections are being studied, and in what journals they are being published.

Due to the increase in research and publications of skeletal collections, there has been rising concern on how these remains were acquisitioned and the ethics involved when studying human remains in various contexts, including forensic anthropology. Alves-Cardoso and Campanacho (2022) assess that all skeletal collection curators should carefully consider how they received their remains in the past and repatriate those that were unethically sourced. As well as, they emphasize the need to create a lengthier and a more informed consent process to accept donations that were either autopsied or considered “unclaimed” remains (Alves-Cardoso and Campanacho 2022). Implementing these changes aids in creating more ethical skeletal collections which is necessary to properly demonstrate respect and to ensure the success of these collections for long term research and studying.

Additionally, Campanacho et al. (2021) address many specific collections that are being used throughout the world and their concerns for ethical violations. Campanacho and colleagues discuss the history of creating skeletal collections, which predominately were created in the United States from grave robbers for anatomical education (Campanacho et al. 2021). In the midst of graving robbing, in 1831, the Anatomy Act was passed to prevent grave robberies and

allow unclaimed remains to be used for anatomy dissections (Campanacho et al. 2021). Various collections used today such as the Huntington Collection at the National Museum of Natural History and the R. J. Terry Anatomical Collection at the Cleveland Museum of Natural History used unclaimed bodies to create their skeletal collections (Campanacho et al. 2021). Similar issues, including preservation, persist with collections such as the W. Montague Cobb Human Skeletal Collection at Howard University, Washington D.C. In this particular collection, 300 skeletal remains were not cared for or used properly and are no longer able to be studied (Campanacho et al. 2021).

Additional laws such as the Uniform Anatomical Gift Act of 1968, allows individuals to donate their body to science after their passing. This is the process that the University of Tennessee's Donated Skeletal Collection follows. Following the University of Tennessee's body donation program, various Universities in the United States later developed their skeletal collections to become a donation program (Campanacho et al. 2021). Campanacho et al. (2021) justify the use of the skeletal collections by explaining how useful these collections are for learning osteology and pathology as well as researching new anthropological methods. These collections can be used to develop methods and references necessary accurately assess the biological profile of human remains (Campanacho et al. 2021). However, there are limits to these collections, as the majority of collections are not diverse, such as the UTK Donated Skeletal Collection is predominately composed of older European American skeletons (Campanacho et al. 2021).

Measuring Tools

There are various tools available to measure skeletal estimations for stature estimations. Commonly sliding calipers, spreading calipers, and osteometric boards are used to measure the skeletal elements. Giurazza et al. (2012) offers an alternative method to calculate stature to traditional measurement methods that relies on using a CT machine. This method includes taking measurements of the femur and various skull measurements on the various planes and compare it to the height and weight of the individual. This study calculated regression and multiple regression equations and concluded that there can be differences between populations and sexes when using the regression equations (Giurazza et al. 2012). The results of the Giurazza et al. (2012) study emphasizes the importance of using multiple varying regression equations for varying population affinities and sexes.

It is important to analyze and study the methods and tools used to calculate stature to ensure that the most appropriate and accurate tools are being used. In specific cases, there are claims there are shortcomings with anthropological tools including sliding calipers. Osquei and Rousta (2012) compared the accuracy and functionality of types of sliding calipers. They found that the tools were not always accurate and suggests ways to improve the tools, accuracy, and precision of the measurements necessary for stature estimation (Osquei and Rousta 2012). Improving the accuracy of the tools used is highly important in order to effectively use new methods to calculate stature.

Other Stature Methods

Alternative methods are developed to aid in the ability to calculate stature in unique situations that do not allow for the use of traditional methods, such as the anatomical method or

Simmons et al. (1990). One alternative method to estimate stature involves using 3D rendering to reconstruct partial femurs (Ebert et al. 2022). The rendering allows for the analysis of the femur and measurements to be taken in order to calculate stature. Ebert et al. (2022) used various methods to calculate statistical equations to estimate the stature. Overall, the study concludes that the stature estimations were fairly accurate using the statistical shaping model, with the femur measurements usually being 1 mm from the actual length (Ebert et al. 2022).

In a different method, Gidna and Domínguez-Rodrigo (2013) measure the linea aspera of the femur to calculate the stature. The collections used were a varying population affinity, composed of 130 ancient Spanish remains from the University of Madrid (Gidna and Domínguez-Rodrigo 2013). This study measured each measurement three times and used the average as their final measurement for statistical analysis (Gidna 2 and Domínguez-Rodrigo 013). The R program was used to perform regression equations (Gidna and Domínguez-Rodrigo 2013). The study created a regression equation using the linea aspera to calculate the entire femur length (Gidna and Domínguez-Rodrigo 2013). This study has significant implications, as it is using a differing population affinity from the commonly modern European male and female populations, as well as explores useful statistical models.

Lastly, an additional study organized the remains into three groups by their estimated or projected stature and created a formula for each group based on the average anticipated stature. Each group was associated with a multivariate regression equations based on the group stature (Duyar et al. 2006). However, this study was performed on living individuals and is not able to be translated to forensic cases involving only bones and no soft tissue (Duyar et al. 2006). Despite this, the researcher states the purpose of the study was to offer a method, grouping by heights, that can be then applied to forensic anthropology cases (Duyar et al. 2006). This method

can be applied to human remains by organizing the remains by their projected height and then performing regression analysis of their measurements in order to create regression equations for the population.

Significance

Calculating stature is critical for developing an accurate and reliable biological profile in order to identify remains. To calculate stature, Krishan and colleagues suggest using the anatomical method and when not possible, a regression formula which entails using the measurements from partial or fragmented remains to estimate the height (Krishan et al. 2012). Krishan and colleagues suggest using FORDISC 3.0 as an alternative method to calculating stature when possible. They also address the importance of population affinity, age, and asymmetry in calculating stature. Each category can significantly influence the calculated height of the individual, with different races having different traits, deterioration with age, and unequal lengths in long bones (Krishan et al. 2012). This emphasizes the importance of identifying the sex and population affinity of the remains prior to attempting to calculate stature, in order to produce the most accurate results.

De Boer et al. (2020) describe various forensic cases involving significant disasters where remains are frequently fragmented, including the 9/11 New York terrorist attack that resulted in 22,000 bone fragments and over 2,100 fragments from the flight 587 plane crash. They describe the necessity of forensic anthropologists at these types of disaster scenes to identify the bone fragments and identification of the individuals (De Boer et al. 2020). These mass disaster situations that result in fragmented remains are unfortunately not uncommon and reinforce the need for accurate and reliable methods in order to identify fragmentary remains.

In continuation, the importance of calculating stature from fragmentary remains aids identification not only in mass disasters but also fragmentary remains of unidentified migrants with fragmentary remains (Pilli et al. 2023). Pilli et al. (2023) describe the dangers of being a migrant and how there were over 25,000 migrants dying in the Mediterranean from Africa to Europe with in the last ten years. Researchers discuss the challenges in estimating the sex and population affinity of these unknown individuals, limiting accurate stature and age estimates of the individual, as those methods are built on the sex and ancestry of the individual (Pilli et al. 2023). Philli et al. (2023) highlights the importance of establishing accurate ancestry estimations before continuing to stature estimations, as ancestry plays a significant role in calculating stature.

Fragmentary Stature Estimations

Steele and McKern developed an equation to calculate stature for fragmentary remains based on their analysis of 117 skeletal remains of male and female Native Americans recovered in Arkansas near the Mississippi River (Steele and McKern 1969). They used 5 different measurements of the femur to calculate the stature, including the proximal point of femoral head, mid-point of lesser trochanter, proximal point of popliteal surface, proximal point of intercondylar fossa, and the medial condyle. Steele and McKern (1969) organize their formulas by the segment of the femur available to measure. They divide the femur into four parts and have an equation associated with the segment that is measured, as well as measuring multiple segments or a larger portion of the femur. They provide regression equations for each measured segment as well equations when multiple segments of the femur can be measured (Steele and McKern 1969). Once the length of the long bones is calculated using the equations, Steele and McKern (1969) suggest adding 9 mm to the measurement to account for statistical errors. The

measurements are separated by sex, emphasizing the necessity of using the sex specific formula to calculate the stature (Steele and McKern 1969).

In response to the Steele and McKern (1969) method, Simmons et al. (1990) calculated a regression equation to estimate the stature using fragmentary femurs of both sexes and multiple populations. Simmons et al. (1990) measured 800 remains from the Terry collection composed of white, black, male, and female remains. To create a more accurate formula, the Simmons et al. (1990) study standardizes the measuring process by using landmarks on the bones as measuring points, rather than measuring relative portions of the bones. Nine different landmarks are used in this formula including, the vertical diameter of the femoral head, epicondylar breadth, and medial condyle height (Simmons et al. 1990). Simmons et al. (1990) provides regression equations of stature and femur length that are specific to each measurement, ancestry and sex. These equations include a slope, intercept and a standard error for each measurement (Simmons et al. 1990). For the vertical diameter of the femoral head of white males, the equation of height is $1.11 * (\text{measurement}) + 113.89$, with a standard error of 6.77 (Simmons et al. 1990). The Simmons et al. (1990) regression equations provide more standard measurements than Steele and McKern (1969) who offered segments that are difficult to standardize among researchers and forensic anthropologists. In addition, Simmons et al. (1990) provides, sex and population affinity specific regression equations, which lead to more accurate calculations as population affinity and sex can impact stature.

Research Question

The goal of this current research is to assess the accuracy of the Simmons et al. (1990) regression equations on a modern sample with known living stature. The research question

central to this paper is: How accurate are the Simmons et al. (1990) regression equations? In order to answer this question, I will use the measurement of the femoral vertical head diameter from the white males of the UTK Donated Collection. This equation calculates the stature using the proximal portion of the femur only, which is applicable for many forensic cases involving fragmentary remains. The resulting stature will then be compared to the known or reported stature for accuracy.

Methods

To answer the research question, the data set consisted of white males, aged 19-69 years with a mean age of 52.8 years, from the University of Tennessee, Knoxville Donated Skeletal Collection. Data was collected from 60 donors, all of which excluded hip replacements or significant pathology present at the head of the femur. All 60 donors had a cadaver stature, estimated living stature, and measured vertical head diameter. The director of the Forensic Anthropology Department provided a list of 100 donors in the collection that best fit the description. The remains were selected from that list based on access as well as those that were physically present and not already removed for teaching or research purposes. Each right and left femur were removed from the storage box, and the vertical diameter of the femur head was measured using sliding calipers. After measurements, all femurs and elements were carefully repackaged according to the collection's procedure.

A total of 120 femurs, 60 right and 60 left, were measured. For each femur, the vertical head diameter (VHD) was measured three times with a sliding caliper. The VHD measurement was taken by placing immovable end of the calipers at the top of the femur head and the sliding side was placed at the distal most end of the femur head and moved to find the maximum measurement. Between each measurement, the measurement was entered into the data sheet and

the calipers were reset. For the first 44 femurs, manual sliding calipers were used, and on femurs 45-120 electronic Absolute AOS Digimatic sliding calipers were used. Each measurement was performed three times and the average was calculated for each femur. These averages were used to estimate the stature using the Simmons et al. (1990) regression equation: $\text{stature} = 1.1(\text{vertical head diameter}) + 113.39$.

The data sheet used to record the measurements, includes the assigned study number for each femur, the collection number, age, reported height, and cadaver height. For confidentiality, the UTK collection number is only recorded on the original and confidential data sheet. A replica data sheet excluding only the collection number was utilized for the remainder of the study for all data analysis and interpretations.

To analyze the Simmons et al. (1990) regression equation beyond the difference between the calculated stature, and the known stature, all statistical analysis were preformed using R Studio version 4.4.2 (2024). To assess the accuracy of the initial observations the measurements taken were compared to the UTK reported VHD measurement. The spread of the data, including the minimum, maximum, and median, was calculated using the R summary function as well as the standard deviation function. The correlation function was also used as well as the ggplot2 function to analyze the correlation of the data. Lastly, a t-test was run to assess the difference in means of the calculated stature from the taken measurements and the reported measurements. After analyzing the accuracy of the measurements taken, the stature calculated was compared with the cadaver and the estimated stature using t-tests. Two t-test were run, one for each comparison, and the p-values were analyzed for the difference in means.

To confirm that the measurements taken and the calculated stature were correct, a linear regression model was used. The first model inputs the measured VHD and the calculated stature

to confirm the correct regression equation intercept and slope. After the confirmation, two subsequent linear regression models were calculated; one was using the VHD measurements and the cadaver stature while the second one used the estimated stature. Each regression model offers a slope and intercept that best fits for the given measurements and expected stature given that it is either cadaver or estimated stature.

Results

A total of 120 femora were measured from 60 donors (both left and right). The VHD measurement averages taken range from 45.33 to 52.66 mm. The average measured calculated stature of the sample measured is 166.134 cm (5'5.403"). Using the Simmons et al. (1990) method, it is recommended to use +/- 6.77 cm in the estimation to account for standard error. Therefore, the average estimated range of stature for the population mean is 159.354-172.894 cm. This range does almost include the average cadaver stature; however, it does not include the average estimated stature. The table below lists the average statures for the measured VHD, calculated VHD, estimated and reported stature.

	Mean Stature (cm)	Mean Stature (inches)
UTK Measured VHD Stature	166.1 cm	5'5.4"
UTK Reported VHD Stature	166.8 cm	5'5.7"
UTK Estimated Stature	178.0 cm	5'10.1"
UTK Cadaver Stature	173.2 cm	5'2"

Table 1: Stature Averages for All Samples

Interobserver Error

The range of measured of calculated statures from measured VHD is 158.3-172.3 cm and the range for the reported VHD stature is 118.3-173.8 cm. The standard deviation of the measured calculated stature is 2.973 cm and 5.241 cm for the reported calculated stature. A correlation of 0.438 was calculated using Pearson's correlation coefficient. This method calculates a number ranging from -1 to 1. The positive value indicates that there is a positive correlation between the measured and reported statures (Collins-Elliot 2025). As well as the following graph, Figure 1, illustrates the correlation between the two measurements with A1 being the mean calculated stature, and B1 being the reported calculated stature.

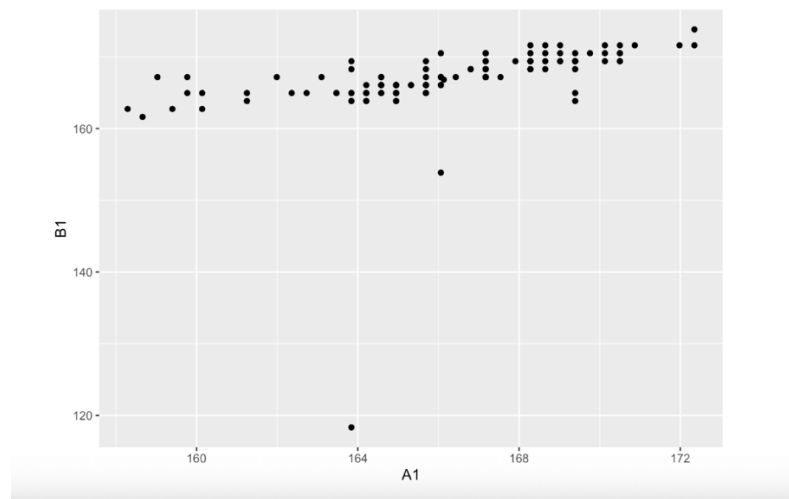


Figure 1: R ggplot2 of Correlation of Mean Calculated Stature and Reported Calculated Stature

A t-test was performed for interobserver error between the UTK reported measurements, and the measurements taken for this current research. Using Welch's T-test in the R program, the p-value for the measured calculated stature and the reported is 0.213. Using an alpha of 0.05 to

assess this p-value and a null hypothesis that there is no difference in means, the null hypothesis would be accepted (Collins-Elliot 2025).

Calculated Stature

The averages of the VHD were used to calculate stature using the Simmons et al. (1990) regression formula. The results of the formula provide a stature and using the standard error, it includes a range of ± 6.77 . The mean of the measured calculated height was compared to the cadaver and estimated stature of the donor. As shown in the following figures, there is a difference in the estimated and cadaver stature, as well as the mean calculated stature.

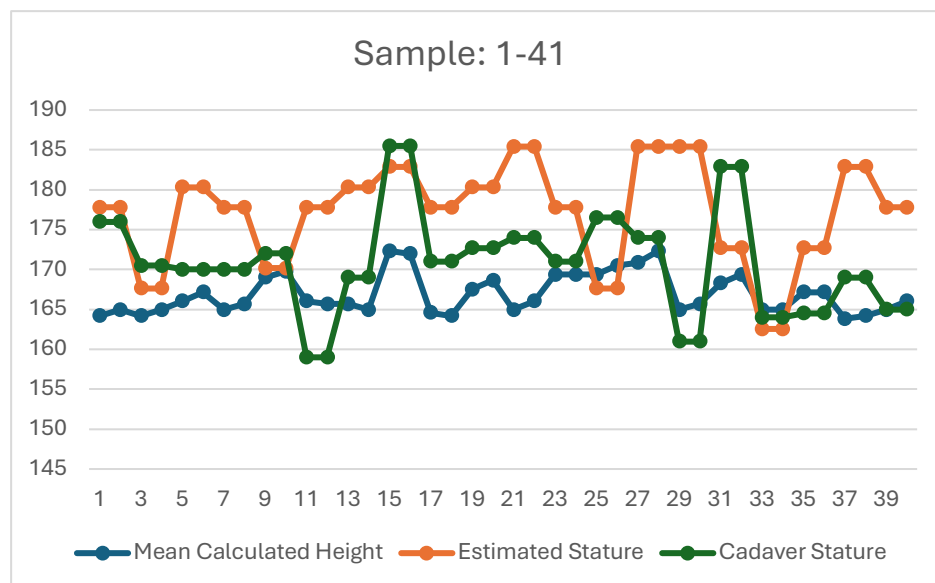


Figure 2: Sample 1-41 Stature Comparison

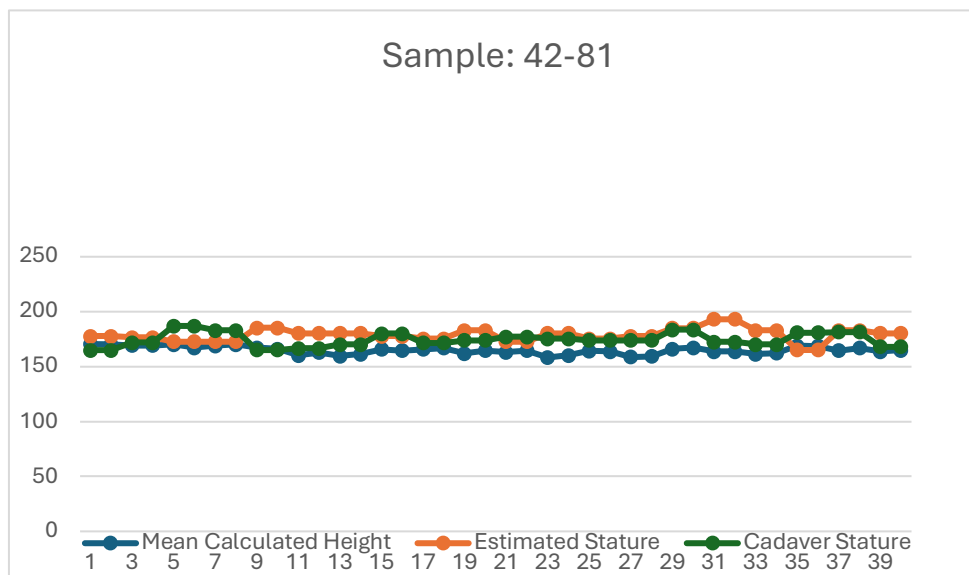


Figure 3: Sample 42-81 Stature Comparison

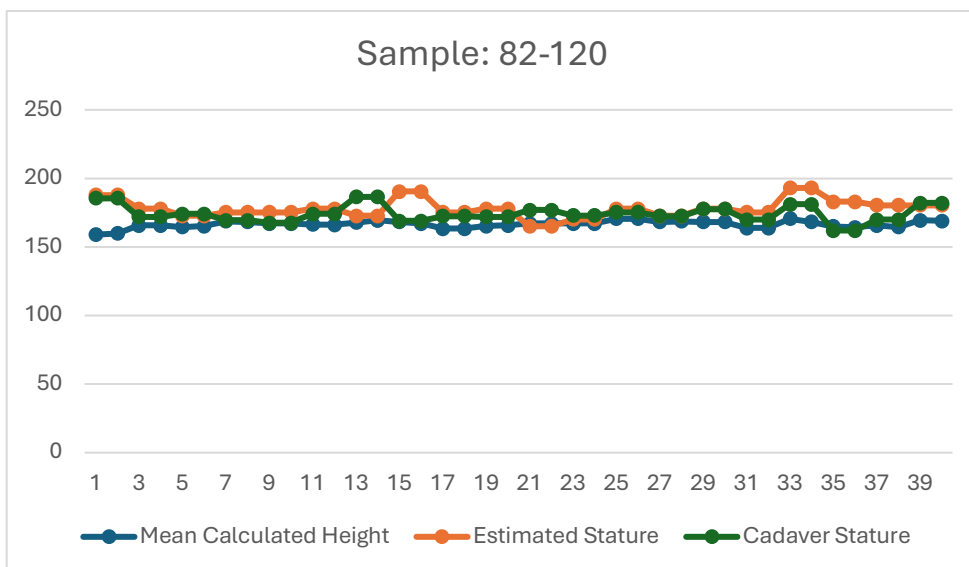


Figure 4: Sample 82-120 Stature Comparison

Figure 2 with samples 1-41, shows a greater difference between the three statures, than Figures 3 and 4. Samples 42-120 show a difference between the calculated, estimated, and cadaver stature; however, it is far less than those present in the first samples.

To analyze the correlation between the measured calculated stature and the estimated stature a t-test was performed, as demonstrated in Figure 5. The Welch's T-test performed in R indicates that there is a difference in means since the p-value is nearly 0 which is less than the alpha of 0.05 (Collins-Elliot 2025). Therefore, the alternative hypothesis that there is a difference in means is accepted. Similarly, as shown in Figure 6, the measured calculated stature and the cadaver stature were compared using the t-test in R and yielded the same results.

```
E <- dat[!is.na(dat$Estimated.Stature), ]
E1 <- E$Estimated.Stature
t.test(A1, E1)

##
##  Welch Two Sample t-test
##
## data:  A1 and E1
## t = -18.821, df = 171.6, p-value < 2.2e-16
## alternative hypothesis: true difference in means is not equal to 0
## 95 percent confidence interval:
##  -13.09292 -10.60735
## sample estimates:
## mean of x mean of y
##  166.1340  177.9841
```

Figure 5: R coding of Measured Calculated Stature and Estimated Stature T-Test

```
D <- dat[!is.na(dat$Cadaver.Stature), ]
D1 <- D$Cadaver.Stature

t.test(A1, D1)
```

```
##
## Welch Two Sample t-test
##
## data: A1 and D1
## t = -11, df = 169.57, p-value < 2.2e-16
## alternative hypothesis: true difference in means is not equal to 0
## 95 percent confidence interval:
## -8.317181 -5.786152
## sample estimates:
## mean of x mean of y
## 166.1340 173.1857
```

Figure 6: R coding of Measured Calculated Stature and Cadaver Stature T-Test

New Solution: Cadaver Stature

For this population, the Simmons et al. (1990) equation does not provide a stature estimation that matches the best fit for this data as shown in the t-tests performed. Therefore offering an alternative equation is important in order to accurately estimate the stature of this population of modern, white, males, of an average age of 52.8 years old. Using the R program, linear regression models were performed to calculate an equation that best fits the measurements taken and the estimated and cadaver statures (Collins-Elliott 2025). First, a regression model was used to test the accuracy of the measurements and calculated statures using the Simmons et al. (1990) regression equation. The summary function lists the R^2 or coefficient of determination as 1 for this model. The value being 1 indicates that the measurements used all fall on the regression line formed with the model (Collins-Elliott 2025). Below, Figure 7, demonstrates the input of the VHD measurements and the calculated stature.

```
C <- dat[!is.na(dat$VHD.Mean), ]
C1 <- C$VHD.Mean

model <- lm(A1 ~ C1, dat)
model
```

```
##
## Call:
## lm(formula = A1 ~ C1, data = dat)
##
## Coefficients:
## (Intercept)          C1
##      113.89         1.11
```

```
summary(model)
```

```
##
## Call:
## lm(formula = A1 ~ C1, data = dat)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -3.220e-09 -3.207e-09  4.892e-10  4.934e-10  4.197e-09
##
## Coefficients:
##              Estimate Std. Error  t value Pr(>|t|)
## (Intercept) 1.139e+02  4.146e-09  2.747e+10  <2e-16 ***
## C1          1.110e+00  8.794e-11  1.262e+10  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 2.581e-09 on 119 degrees of freedom
## Multiple R-squared:  1, Adjusted R-squared:  1
## F-statistic: 1.593e+20 on 1 and 119 DF, p-value: < 2.2e-16
```

Figure 7: R Program- Linear Regression Model with Calculated Stature

```
model <- lm(D1 ~ C1, dat)
model
```

```
##
## Call:
## lm(formula = D1 ~ C1, data = dat)
##
## Coefficients:
## (Intercept)      C1
##   147.7313     0.5408
```

```
summary(model)
```

```
##
## Call:
## lm(formula = D1 ~ C1, data = dat)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -14.1496  -3.6088  -0.8061   3.7517  15.6956
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  147.7313    10.0479   14.703  <2e-16 ***
## C1           0.5408     0.2131    2.537   0.0125 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 6.254 on 119 degrees of freedom
## Multiple R-squared:  0.05133,    Adjusted R-squared:  0.04335
## F-statistic: 6.438 on 1 and 119 DF,  p-value: 0.01246
```

Figure 8: R Program- Linear Regression Model with Cadaver Stature

Figure 8 represents the R coding run to calculate a linear regression model using the VHD measurements and the cadaver stature. The model suggests using 0.5408 as the coefficient and 147.7313 as the intercept. The model lists the R^2 value as approximately 0.05 which indicates that the measurements used for this model, do not fall as close to the line. The closer the number falls to 0 the farther the points are from falling perfectly on the line as they do in Figure 7 (Collins-Elliot 2025). The equation of Figure 8 can still be used to input VHD measurements and most accurately calculate the cadaver stature of this population.

New Solution: Estimated Stature

The following figure, Figure 9, depicts the R calculations of the linear regression model using the VHD measurements and the estimated stature (Collins-Elliott 2025). The model suggests using the coefficient of -0.4135 and the intercept of 197.445 to calculate the stature. The R^2 value of this model is approximately 0.03 which is lower than the cadaver R^2 value of Figure 8, indicating that the measurements of this model far father from the model's regression line. This equation is to be used to calculate a stature that best represents the estimated stature of the skeletal remains.

```
model <- lm(E1 ~ C1, dat)
model
```

```
##
## Call:
## lm(formula = E1 ~ C1, data = dat)
##
## Coefficients:
## (Intercept)      C1
##   197.4450    -0.4135
```

```
summary(model)
```

```
##
## Call:
## lm(formula = E1 ~ C1, data = dat)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -15.8652  -3.7165  -0.2413   3.3522  16.6822
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  197.4450     9.9319   19.880  <2e-16 ***
## C1           -0.4135     0.2107   -1.963   0.052 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 6.182 on 119 degrees of freedom
## Multiple R-squared:  0.03135,    Adjusted R-squared:  0.02321
## F-statistic: 3.852 on 1 and 119 DF,  p-value: 0.05203
```

Figure 9: R Program- Linear Regression Model with Estimated Stature

Discussion

Calculated Stature

Calculated stature using the Simmons et al. (1990) equations and reported measurements are statistically similar. However, the measured stature calculations do not compare as well to the cadaver and estimated statures. The measured calculated statures are a far underestimation from either the cadaver or estimated statures. Even when attempting to include the ± 6.77 cm range, they still do not most accurately include the cadaver nor reported statures. The p-value also indicates that there is a difference in means when comparing the calculated stature and the cadaver and estimated statures. This indicates that the Simmons et al. (1990) equation is not the best equation for this sample of middle-aged, modern, white male remains.

New Linear Regression Equations

In order to attempt to calculate an equation that more accurately represents the statures of this population, the R program and linear regression model was used. This method created two equations that were a better fit when comparing the measurements taken and the cadaver and estimated stature. These equations can and should be applied to this population and remains that are very similar to this population. The cadaver and estimated stature are both varying slightly to account for the discrepancies that often occur between the two statures. Therefore, each one should be used when trying to obtain the respective height.

Limitations

There are limitations to this project, including a small sample size or possible observer error. This project's sample size consisted of 60 remains and 120 measured femurs. However,

the sample size could be expanded to a much larger scale project in order to develop more accurate equations with increased data. Additionally, there are a few of the measurements where there is a possibility of observer error. This includes placing the calipers in the incorrect spot for the measurement or mistakenly measuring the same femur instead of the separate right and left femur. As well as, after the 44th femur, the mechanical sliding calipers were replaced with electronic calipers. The difference in measuring instruments could impact the data collected. As well as, errors could have occurred with the electronic calipers, such as not being calibrated or zeroed out after every measurement. Lastly, the conclusions drawn with the linear regression model are minimal and require increased statistical practice in order to prove their usefulness as a method and accuracy. Subsequent data collection and deeper statistical analysis is needed in order to calculate the most accurate regression equation for this data set.

Importance

The ability to calculate stature that is the most accurate is extremely crucial. Stature is a vital part of the biological profile that is used by forensic anthropologists to identify skeletal remains. In order to identify the remains, the stature calculated needs to be accurate in order to compare it to the estimated stature of the unidentified remains. This sample population is evident that the Simmons et al. (1990) equation does not lead to a stature estimation that is within the range of either the estimated or cadaver stature. Therefore, accurate equations are necessary that are modified to account for these differences. The respective equations are the most accurate for the difference in the two separate stature estimations.

Conclusions

The results of this study conclude that the Simmons et al. (1990) regression equations are not the most accurate equations to be used on the middle-aged white males of the UTK Donated Skeletal Collection. The equations led to a stature estimation that is significantly lower than both the cadaver and estimated stature. However, when comparing the vertical head diameter measurements with the cadaver and estimated statures, a linear regression model can be used to calculate a more accurate regression equation. These equations calculate are the most current and accurate equations to be used on this population when attempting to calculate the stature of fragmentary remains of similar age, sex, and population affinity.

Technical Note

The statistical analysis was largely calculated using the R statistical program, including Figure 1 and Figures 5-9. The following software and packages were used to perform the statistical models described in this paper. The remainder of the functions used to perform the statistical analysis are the basic statistic packages included in the R program.

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