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In this thesis, stature reconstruction of three prehistoric/protohistoric Native American populations (from Alaska, the Aleutian Islands, and South Dakota) was performed using the Fully Anatomical method in order to formulate regression equations and analyze the ability of regression equations of other researchers to accurately estimate the statures within my study populations. The calculation of regression equations demonstrated that even though there was a significant difference in the statures of the three populations, they were similar enough in body proportions such that regression equations from the pooled sample could be used to accurately estimate statures from all three groups as well as 12 randomly chosen individuals from outside the study sample.

Results of statures calculated using the regression formulae of other researchers on my sample populations forced me to conclude that there is too much variation between populations to allow for much inter-populational applicability except in those cases where the populations are similar enough in proportion. For my study groups, the best equations for estimating statures (*besides the ones formulated specifically for them*) were those of Sciulli et al. for Ohio native Americans, followed closely by Trotter and Gleser's 1952 and 1958 equations. The femur/stature ratio of Feldesman et al (1990) performed relatively poorly, and the formulae of Genoves' for Mesoamericans (1967) were the least accurate.

While individual statures may be more highly influenced by genes, the mean statures of populations or homogeneous geographical groups is more controlled by common levels of nutrition, stress, and environment of the individuals within that group. The Arikara were the tallest population: the female mean of that group were as tall as the male means from both the Alaskan and Aleutian populations. The populations in this study differed in their degree of sexual dimorphism, with the Arikara individuals showing the greatest stature difference and dimorphism between males and females. The distal limb bones of the arms and the legs of the individuals from both Alaska and the Aleutian Islands show significant shortening when compared to those of the Arikara, supporting "biogeographical" rules of human adaptations to chronically cold environments.

The results of this study illustrate how important it is for researchers to keep studying (and publishing regression equations for) statures of prehistoric and historic populations. Until someone develops a formulae that can truly be applied to populations everywhere—as the femur/stature ratio and the line of organic correlation attempted to—there is too much variation between groups to allow researchers to continue to apply equations not applicable to their population.

The Long and Short of It: The Reliability and Inter-Populational Applicability of Stature Regression Equations

by
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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Donna McCarthy, Author

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INTRODUCTION

Reconstructing the stature of individuals from prehistoric or early historic populations can add substantial information about the conditions under which those people lived as well as creating a more complete picture of their physical appearance. Were the individuals tall or short? Were they relatively stocky and robust? Were they under physical or nutritional stresses? Stature is more than just a measurement of how tall a people were—it can provide unusual insights into other areas of their lives as well. Unfortunately, even with all its potential uses, there have been relatively few studies of stature published to date.

The first, and most obvious, use of stature estimation is in the identification of an individual from discovered skeletal remains, particularly if the remains are fragmentary or incomplete. This is not a new problem—as a matter of fact, the identification of casualties of war was a major impetus for the study of stature as far back as 1944. Identification laboratories were set up as part of the United States Repatriation

Program established by Congress to provide identification for unknown American war dead (Trotter and Gleser, 1952). The rapidly expanding field of forensic anthropology has rekindled interest in stature reconstruction because *accurate* stature estimation can be an important factor in the identification of an individual, especially when only partial remains are found. An inaccurate estimation of an individual's height could substantially slow their eventual identification to a specific missing person, casualty of war, or victim of a violent crime.

Statures may also be used to illustrate the effects of climatic forces on populations. Specific trait differences related to environmental conditions had been noted in many warm-blooded species throughout the world for centuries. This prompted scientists to formulate specific "biogeographical rules" to explain these differences. The most well-known and widely cited are Bergmann's rule (1847) and Allen's rule (1877). Both of these rules apply to adaptations that either prevent body heat loss or allow for heat dissipation by reducing or increasing the surface area of the body.

Bergmann's rule states that warm-blooded species in cold climates will have larger body sizes than those in warmer climates (Beall and Steegman, 2000:177). Increasing body size reduces the skin surface in relation to the individual's mass, reducing the amount of heat lost through the skin, and appears to be adaptive in chronically cold climates. Shortening of the extremities in relation to height—Allen's rule—helps to further reduce the body surface that contributes to heat loss. The opposite adaptations can be observed in warm-blooded species residing in warmer climates, resulting in taller and narrower individuals with lengthened limbs (especially distally) that help to reduce heat build-up within the body by increasing the skin surface through which cooling can take place.

While exceptions to these rules can be cited for many taxa in the animal kingdom, Newman (1953:313) contended that, because we are a single species which has an enormous distribution accompanying great variations in climate, "Bergmann's and Allen's rules may be more closely operative in man than in other animals." Studying the statures--and limb proportionality--of populations in distinct geographic areas and climatic extremes could provide evidence either supporting or refuting the applicability of these biogeographical rules to human populations. Even estimated statures that don't follow these "rules" can be valuable, as they may indicate other factors at work, such as other environmental stresses or even migration.

Sexual dimorphism, the difference in overall size between males and females of a species, has also been examined in part using stature. Although stature in itself is insufficient in the study of dimorphism due to confounding factors (Hall, 1978), it can be used in conjunction with other measurements, such as long bone shaft diameter and humerus head diameters to support evidence of dimorphism.

Sexual dimorphism exists for virtually every human population, although not to the same extent, and the stature difference, (in favor of the males) had been shown by Eveleth (1975) to vary from four to eight centimeters. However, Eveleth's research was subsequently shown to be irrelevant because it was based on a concept of "major continental race" or "ethnic group" that incorporated into large groups smaller groups that each may have been affected by its own microclimate, geography, nutrition, and behavior (Hall, 1982:190).

While dimorphism in itself is an interesting phenomenon, it is changes in this size difference (either increases or decreases) that have sparked a great deal of research. Studies too numerous to detail here have been undertaken in the past (and continue to be conducted today) to explain why these changes may occur. Genetics and environment are the two most common explanations.

Changes in the environment that altered diet and nutritional resources also affected the rate of growth in the femur and tibia (Larsen, 1987). These changes, (including both climate and behaviors, such as the transition from hunting and gathering to agriculture) resulted in changes in the degree of sexual dimorphism within many prehistoric populations (see Hamilton, 1982; Buikstra, 1984; Cook, 1984; Larsen, 1984). In many cases, a greater stature loss was observed for males than for females. Females appear to be more resistant to nutritional and environmental stresses than males, possibly due to a greater capacity for storing nutrients (Larsen, 1987) or some internal buffer due to their bodily requirements for pregnancy and lactation, although the exact mechanisms are unknown (Stinson, 2000).

One exception to this was observed in prehistoric Georgia coastal populations after A.D. 1150, the time period in which many groups intensified their reliance on agriculture (particularly maize). In a study comparing pre- and post-agricultural sites, Larsen (1984) found that while skeletal size decreased for both males and females, it was the females who experienced the greater reduction overall. Stature decreased from

2.7 to 2.9% for females, and only 0.2 to 1.1% for males, with the females also exhibiting a 2.5% greater decrease in skeletal robusticity. Larsen concluded that this difference could be explained not only by a change in diet, but a change in activity as well, stating:

> (I)t is important to keep in mind that female physical activity patterns may (have been) more altered with the shift to sedentism than those of males…women may have had a less mechanically demanding behavioral repertoire than males after A.D. 1150 and, hence, a relatively greater reduction in bone area and skeletal size (1984:385).

Studying the patterns of stature within a single burial site has been done to demonstrate differences of status, in that those individuals with greater access to food resources may be taller than those suspected of being of lower status within the group. In her 1984 study, Jane Buikstra examined the statures of individuals in the Lower Illinois Valley during the early Late Woodland Period. Buikstra demonstrated that the males of higher status (indicated by preferential burial treatment) were an average of 3.3 centimeters taller than those of lower status, while no apparent stature difference was observed between females of high and low status.

Changes over time, both within a single population and between populations of different time periods, have also been examined. Changes in standard of living, such as improvements to sanitation, living conditions, and health care also brought about changes in stature. Tanner estimated that people have increased in stature at a rate of one centimeter per decade since 1850 (Himes and Mueller, 1977), although subsequent studies have not always supported this estimation. Fluctuating changes in stature over the last 85 years—as opposed to the gradual, progressive change hypothesized—were illuminated by two consecutive studies of stature on European and African Americans conducted by Mildred Trotter and Goldine Gleser in the 1950's (Krogman, 1973). Hall (1978) also demonstrated that changes to 19th century Northwest Coast populations over time were not constant because the two sexes responded to the environment differently.

Contact between Europeans and Native Americans also brought about changes in long bone length that can be seen in the archaeological record. In a comparison of diaphysis lengths for perinatal skeletons from early and late contact periods, Owsley and Jantz demonstrated a reduction in length for those of the late contact period (Larsen, 1987). Different environmental changes, such as "Old World infectious diseases, increased tribal warfare (and) Euroamerican territorial expansion" (Larsen, 1987:347) were believed to have been likely stressors.

If early reductions in bone length indicate a depression of growth rates, adult body size could also be compromised.

The extent to which genes control adult stature is not well-understood, as there appears to be a complex relationship between genes and the environment in which an individual lives. As Tanner stated (1994:2), "an individual's adult height does indeed reflect the degree to which the environment has frustrated or contorted the plans put forward by his genes." Apparently, the environment has its greatest chance of affecting future stature very early in life, between the ages of six months to three years, and differences caused by genes generally manifest between the ages of three and puberty (Tanner, 1994:3). Early childhood growth faltering caused by environmental factors can be made up during "catch-up growth" in adolescence, a period of growth which appears to be little affected by environmental conditions (Stinson, 2000); however, this "catch-up growth" may also lead to serious health consequences not associated with an increase in stature later in life.

The uses above are among the reasons I chose to study stature for this thesis--especially with the paucity of stature studies in recent literature. If researchers are to interpret past environmental conditions and behaviors in part by examining stature, they must first be able to accurately measure it. The difficulty that arises from the shortage of published stature studies is that anthropologists are often forced to use stature regression equations inappropriate for the individual whose stature they are attempting to estimate. It was my hope when I began my research that I would be able to create stature regression equations for populations not previously published, increasing the number of formulae that other anthropologists could potentially utilize. To do this, I needed to assess what others before me had done in this area.

Contrary to being the straight-forward process I assumed it would be, my research began to indicate just how complex the history and process of stature reconstruction could be. From one study to the next, there appeared to be no consensus regarding the condition of the bones to be measured or the techniques used to measure them. Compounding this was the fact that the effect of aging on stature, the difference between cadaver height and living stature, and the inter-populational applicability of regression equations varied between populations. In the next chapter, I present a history of stature reconstruction research from the late 19th century to the present which will illustrate the difficulties and controversies encountered in the research and how the researchers who followed attempted to support or dispute the claims made by those before them.

As I read reports of those before me and the complexity of stature reconstruction became clearer to me, I formulated three research questions that I wanted to answer within this thesis:

1. What is the best (most accurate) method for reconstructing stature?
2. Do population-specific statistics matter in stature reconstruction?
3. How do body proportions contribute to stature differences between groups and what effect do they have in inter-population applicability of regression equations?

To answer these questions, I collected human skeletal data from several museum collections. In a process that is examined in great detail later in this thesis, I collected measurements of the skull height (known as BBH or basi-bregmatic height), the maximum anterior heights of the presacral vertebrae (C2 through L5), the maximum height of the first sacral segment (S1), the bicondylar length of the femur, maximum length of the tibia, and the articulated height of the calcaneus and talus (ankle height) to be used in stature reconstruction. I also took maximum length measurements of the long bones of the arm (humerus, radius, and ulna) which I used in a further investigation of body proportion. All these measurements were subjected to statistical analyses that are examined in detail in later chapters.

BACKGROUND RESEARCH

ROLLET, 1888

The first serious attempts at stature reconstruction took place in the late 19th century. In 1888, the French scientist Etienne Rollet's "La Mensuration des os Longs des Membres," was one of the first significant studies of its kind. Rollet's study sample consisted of 50 male and 50 female cadavers from hospitals in Lyons, France. They ranged in age from 24 to 99 years (with a mean age of 60), and were relatively short-statured; the females averaged five feet tall, and the males, five feet, five inches (Keen, 1953).

Rollet measured the cadaver lengths on a graduated stretcher usually within one week after the individual's death, and then removed the soft tissue from the bones (Trotter and Gleser, 1952). All the long bones were measured shortly after dissection (before being given sufficient time to dry out), and some were measured again less than a year later. Rollet discovered that the dry bones were two millimeters shorter than they were when measured in their fresh state. As a consequence, anyone wanting to use the tables created by Rollet to determine living stature would first need to add two millimeters to the lengths of the long bones (Trotter and Gleser, 1952:464).

From his measurement data, Rollet constructed the aforementioned tables from which one could determine *the length of a long bone* for each of his stature groups (Telkka, 1950:104). In other words, he assumed that a long lower limb bone would *always* result in a tall stature and vice versa. Limb bone length and stature are not always inversely proportional; as Stevenson would show in his study comparing Chinese and French individuals more than 40 years later, "with shorter limb bones the Northern Chinese are nevertheless taller than the French" (Stevenson, 1929:311).

MANOUVRIER, 1892

To turn around this "anthropological paradox" (Telkka, 1950: 104), Manouvrier re-examined Rollet's data in 1892, proceeding with the idea that the starting point for stature reconstruction should be the length of the long bone or bones responsible for a resultant stature and not the other way around. He first began by eliminating 51 individuals (more than half Rollet's original sample) because they were over the age of 60 at the time of death. He did so because it was well known that after a certain age, people began to lose stature. Although there was no consensus as to exactly when or how quickly this process occurred, Manouvrier estimated that the individuals in Rollet's original study had lost three centimeters of height overall. Aside from removing the older individuals from his study sample, however, he made no other adjustments for the effects of aging on stature (Trotter and Gleser, 1952).

Like Rollet, Manouvrier also created a table from which one could match a long bone length to a calculated living stature estimate. To do this, he arranged two series of long bones (one male and one female) into groups of small, medium, and long based on their lengths. After calculating the mean bone length for each group, "the mean stature of each of the groups was divided by the mean length of the corresponding bone" to produce the "coefficients of the mean: (Length of bone)*(Coefficient) = Stature (Waldman, 1967:43).

For others to use the calculations of Manouvrier, after determining the sex of the individual and measuring the bones in their anatomical positions (that is, the bicondylar femur length and the maximum length of the tibia without the spines), the table would be consulted for the height that corresponded to each bone length. These lengths were averaged, and the mean value was used. Compensation needed to be made for the conditions of the bones being measured. If the bones were dry, two millimeters were added to the length of each bone to compensate for shrinkage that occurred during the drying process.

If the bone length was above or below the limits of his table, the length of the bone was multiplied by Manouvrier's calculated superior or inferior coefficient of the bone (see Krogman, 1973:155). Manouvrier assumed an inverse relationship between long bone length and coefficient, and used this assumption to extrapolate statures for measurements that fell beyond the limits of the table, either being too long or too short (Waldman, 1967:45).

The living height was finally obtained by subtracting two centimeters from the mean value (because of the fact that the cadavers gained an average of two centimeters length due to loss of muscle tone). No consideration was given to issues of ethnicity, as Manouvrier believed that variations between individuals and ethnic groups were essentially equal and that his formulae could be applied both inter- and intra-racially (Waldman, 1967:52).

DWIGHT, 1894

In 1894, the first "anatomical" method for stature reconstruction was utilized in a study conducted by Thomas Dwight entitled, "Methods of Estimating the Height from Parts of the Skeleton" (Lundy, 1985). The anatomical method utilized all the parts of the skeleton that contributed to height as opposed to only the long bones of the limbs. This was an attempt by Dwight to address the issue of variability caused by the disproportion between the trunk and the long bones of the limbs (Fully and Pineau, 1960:146).

Dwight placed the bones of a skeleton in anatomical position and held them in place with clay, estimating vertebral discs within the spine. He measured the individual's height and added additional spacing between "certain bones" totaling 32 millimeters to compensate for missing soft tissue (Lundy, 1985:74). Despite the inclusion of additional parts of the skeleton contributing to stature, however, Dwight's method still caused high degrees of error, similar to those of Rollet and Manouvrier—hardly an improvement considering the difficulty involved in his labor-intensive process.

PEARSON, 1899

Although regression was originally developed by Francis Galton in 1885 to describe the "regression towards mediocrity" (Kurtz, 1999) between the heights of fathers and their sons), Karl Pearson, a mathematics professor, has been given credit for introducing the use of regression formulae into the process of stature reconstruction. Regressions determine the linear relationship between two or more variables, and are expressed as a constant plus a (coefficient * variable

X) plus a (coefficient * variable Y), etc. This new method not only greatly improved the accuracy of stature estimation, but also virtually replaced all methods previously used for stature reconstruction.

Pearson once again used the data originally obtained by Rollet, as Manouvrier had, but he kept all the original individuals, believing that the sample size (49) used by Manouvrier was insufficient for calculating regression formulae for the population. Interestingly, unlike the researcher before him (and many who would follow), he did not feel that *any* correction needed to be made for the effect of aging on stature, stating that whatever small shrinkage might be caused by age "disappear(ed) when a body is measured after death on a flat table (Trotter and Gleser, 1952:465). He calculated a stature loss of only 1.77 centimeters for the older males and .04 centimeters for the older females--both losses smaller than the three centimeters previously estimated by Manouvrier.

Pearson also gave little importance to changes in the conditions of the bones being measured, so that his tables could be used for statures calculated on the living or the cadaver, whether the bones were wet or dry, and whether or not they still contained cartilage. Also, both the maximum and oblique (bicondylar) femur lengths could be used, as Pearson found that the regression coefficients were not changed significantly. If the bicondylar lengths were used, then 0.32 centimeters should be added to the male femur length, and 0.33 centimeters to the female. In addition, Pearson calculated the difference between cadaver length and living stature (in the French population) to be only 1.26 centimeters, not the two centimeters of Manouvrier's study (Waldman, 1967:54).

Although not completely disagreeing with Manouvrier's assumption that stature formulae could be applied across populations, Pearson was the first to recognize that "the extension of the stature regression formulae from one local race…to other races…must be made with very great caution" (Stevenson, 1929:303). As a way to test his assertion, Pearson used both his own and Manouvrier's formulae from the French and tested them against an Aino group. Pearson's formulae resulted in a lower error rate than those of Manouvrier, which supported his theory of "inter-racial applicability" (Waldman, 1967). Interestingly enough, however, an *intra*-population test of his formula--using his formula to estimate the stature of seven executed French criminals of known stature--underestimated their heights by an average of 2.73 centimeters (Keen, 1953:46). Trotter and Gleser (1952:500) attributed this to a possible bias of his original sample in terms of "age, socio-economic status and restricted range of statures."

STEVENSON, 1929

In 1929, Paul Stevenson set out to test Pearson's conclusions regarding inter-populational applicability of stature regression formulae. For his study, Stevenson utilized data from the osteometric records of the Peiping Union Medical College in China. Without having enough material available for females, only data for males was used in his study. He chose individuals from North China whose average stature was 168.8 centimeters, taller than individuals from either central or southern China (1929:306). The sample size was fairly small--only 48 individuals--and only right-sided, well-dried bones were used. After calculating regression formulae for the Northern Chinese, Stevenson compared them to Pearson's French sample.

His results demonstrated that the Chinese were "both absolutely…and relatively significantly less variable than the French" (Stevenson, 1929:306), that the distal limbs of the Chinese had the highest correlation to stature (while the opposite was true of the French), and that, despite having shorter limb bones, the Northern Chinese individuals were still taller than the French (1929:311). When the formulae for the French were applied to the Chinese individuals, the result was underestimated by over four centimeters, and, conversely, when the Chinese formulae were applied to the French, the resulting stature was overestimated to the same degree. Stevenson concluded that stature regressions from one population would result in higher than average error rates, and should best be used to estimate statures on the population from which they were derived. He stated: "In fact, such a difference indicates a statistical improbability of several millions to one that the formulae of one of these two races will provide a satisfactory prediction of the stature of an individual belonging to the other" (1929:310).

As another test of predictability, Stevenson examined the sitting height/stature index of three groups: the original French, the North Chinese, and the Aino. He hypothesized that one might be able to tell in advance which formula(e) might be applicable from one population to another by using those groups whose sitting height/stature indices were closest to each other. The Chinese index of 53.9 was closest to that of the Aino at 54.8 (the French index was lowest at 51.9). He assumed, therefore, that the Chinese formulae should provide a better estimate for Aino stature than the French formulae. His calculations, however, demonstrated that Aino stature was still better predicted by the French formulae than by the Chinese (1929:313).

TELKKA, 1950

Antti Telkka (1950) cited studies by numerous other researchers who also attempted to apply formulae cross-culturally and obtained error rates that made the resulting statures completely unreliable. Of particular interest was Telkka's assertion that the ratio of limb length to stature was an important variable confounding the application of these formulae across populations. He stated, "(O)ne cannot avoid noticing that the ethnical variations are so perceptible as to make the tables which are based on one race in many cases inapplicable to another race without having to allow for the error caused by this ethnical variation alone" (1950:105). Telkka obviously did not share Manouvrier and Pearson's ideas of inter-populational applicability, and because no stature regressions had been done specifically for Finnish material by 1950, he conducted his own study.

Telkka utilized material from 154 individuals (115 males and 39 females) from Helsinki University. The average age of the individuals was 42.3 and 50.4 years for males and females respectively. A "considerable percentage" of the females were over the age of 60 at the time of death, but were left in the study in order to create a larger sample. The average cadaver length of the males was approximately 169 centimeters, and the female length approximately 157 centimeters. After subtracting two centimeters from these means to compensate for living stature, Telkka felt that the females in his study group, due to their high average age at death, were "somewhat below the mean stature" (1950:108).

Measurements of six long bones including the humerus, radius, ulna, tibia, femur, and fibula were taken, and to compensate for asymmetry, a mean value of right and left sides was used (when both sides were present). The condition of the bones at the time of measurement was dry and well macerated. Regression equations for the *cadaver lengths* were calculated on each of the six long bones individually. The calculation of multiple regressions was "given up" due to incompleteness of the skeletal material and because the standard deviation was improved less than 10 percent over that of single bone regressions (1950:110).

When comparing statures obtained by using his own regressions and those of other researchers (including Manouvrier and Pearson), Telkka found that the results were--not unexpectedly due to the nature of regressions --closest in individuals of medium height; however, the formulae other than his own were rather poor for estimating statures of those who were either very tall or very short. Manouvrier's estimates proved to be the least reliable. In a tall female with a femur length of 480 millimeters, for example, the resulting stature was overestimated by 3.8 centimeters; conversely a stature calculated from a male humerus of 300 millimeters (the shortest of the group) was underestimated by 4.1 centimeters.

DUPERTUIS AND HADDEN, 1951

C. Wesley Dupertuis and John Hadden, also recognized the difficulties involved in trying to estimate statures for much taller individuals, and performed their own study in 1951 using skeletal material from the Todd osteological collection at the Western Reserve University School of Medicine. A total of 400 individuals was chosen, 100 of each sex for groups of African Americans and European Americans. The age range for African Americans (between 20 and 45 years) was lower than that of the European Americans, as some older individuals (aged 60 to 65) needed to be included to keep a sample size of 100. The inclusion of 16 females over the age of 60 reduced the overall mean cadaver length, as the females were, on average, 2.5 centimeters shorter than the group mean (Dupertuis and Hadden, 1951:16).

These cadavers had not been measured on a flat table after death as Rollet's had. Instead, with their Achilles tendons cut, "ice tongs were inserted into the ear holes and the body suspended so that the soles of the feet were firmly planted on the floor" (1951:19). This cadaver length, although likely to be slightly short, was taken by the researchers to be a fairly accurate estimate of living stature, so no further consideration was given to it.

The maximum lengths of the femur, tibia, humerus, and radius were measured to the nearest millimeter, and only the right-sided bones were used in calculations. All of the bones were completely dry, having been stored for up to 20 years at the School of Medicine. In construction of new stature formulae for these groups, the researchers considered Pearson's method to be the most reliable, and they calculated regression equations for each individual bone and some bone combinations.

After comparing their own calculations to those of Pearson, Dupertuis and Hadden demonstrated, not unexpectedly, that "each of the formulae gives the best results when it is applied to the population from which it was constructed" (1951:36). As a more interesting result, the data showed that the formulae of Dupertuis and Hadden—based on *tall* individuals of African and European descent—were more accurate in estimating the stature of each other than Pearson's French formulae for estimating the stature of either population.

The greatest deviations between formulae were seen when estimating the stature of the "Whites," and Dupertuis and Hadden believed this was best explained by the ratio of long bones to stature. All of the ratios calculated by Pearson were greater than those of Dupertuis and Hadden's individuals, meaning that Pearson's French had longer leg bones for any given stature. Dupertuis and Hadden then created "general formulae" by "averaging the slopes and origins of the three formulae for the same long bone from each racial group, weighting each according to the number in the respective population" (1951:43).

They retested their new formulae and found that these were better than both their original and Pearson's formulae when estimating the stature of Dupertuis and Hadden's European American sample, reducing the mean deviation from -6.85 to -2.11 (1951:44). For the African Americans, the general formulae gave results that were comparable to those of the population-specific formulae, leaving the researchers to question which formulae should be used to estimate an unknown stature, and under what circumstances. They concluded that the African American formulae should be used for all individuals known or determined to be of African descent. However, for the Americans of European descent, they stated:

> The general rule we suggest is that Pearson's (formulae)should be used when the long bone in question is shorter or close to his mean for that bone, ours should be applied when the long bone is close to or greater than our mean, and the general formulae be used when the length is between the means of the two groups (1951:45).

They extended these rules to the estimation of stature for ancient humans such as Cro-Magnon and Neandertal as well. In each case the mean length of the long bones must be the crucial factor in deciding which formulae is best for estimating the stature of the individual. The researcher's formulae with the closest mean values should give the best overall estimate of living stature.

Not all researchers agreed with the idea of these "general formulae," however. E. N. Keen considered the success of these general formulae as a case of two wrongs almost making a right, stating, "(t)he apparent success of Dupertuis and Hadden's 'general' formulae is partly due to the fact that their own over-estimation is to some extent corrected by Pearson's underestimation" (Keen, 1953:48). Trotter and Gleser (1952) also criticized the use of general formulae, believing that the use of formulae from a "similar" group would yield more accurate results than equations derived from averaging different "racial" groups.

TROTTER AND GLESER, 1952 AND 1958

Mildred Trotter and Goldine Gleser, recognizing the contribution that stature can play in the identification of human remains, the paucity of stature estimation studies done to date, and the problems associated with inter-populational applicability, conducted their own research in 1952. Their sample consisted of male American-born casualties of war (WWII) and individuals from the Terry Anatomical Collection (this collection is discussed in more detail in the materials and methods section of this paper).

Most of the military subjects included for study were young (between the ages of 18 and early 20's), and it was assumed that they had reached their maximum stature with no significant change after the age of 18. The individuals included from the Terry Collection (both males and females) were no younger than 18; however, they reached ages far in advance of the military personnel, and a correction needed to be made for the effect of aging on their statures. The rate of stature loss was calculated to be .06 centimeters per year for every year beyond 30. For "white" males, 1,115 were military personnel, and 255 were taken from the Terry

Collection. The military collection was the source for only 85 African American individuals for this study; the bulk (360) came from the Terry Collection. For females--all taken from the Terry Collection--only 63 were "white" and 177 were African American.

The statures of the military personnel were taken and recorded at the time of induction by many different observers. While the use of one observer for all measurements does decrease the rate of errors (and increase the correlation between variables), it was felt that "this effect (was) relatively small when sufficiently large series of observations (we)re obtained" (Trotter and Gleser, 1952:471). As the statures for the Terry Collection individuals were actually cadaver lengths, a correction needed to be made so that the two samples could be compared directly. As has been shown previously, the same allowance between cadaver lengths and living statures may not be applied to all populations in a general way. Manouvrier, in his 1893 research, concluded that cadavers increased in stature by two centimeters after death. Pearson (1899) estimated an increase of only 1.26 centimeters (Waldman, 1967:54), while Dupertuis and Hadden (1951) accepted the cadaver lengths to be comparable to living stature in their sample. For the Terry Collection individuals, Trotter and Gleser assumed an average reduction of 2.5

centimeters was needed to estimate living stature (1952:493).

They took measurements of six long bones (humerus, radius, ulna, femur, tibia, and fibula), and both the maximum and physiological lengths were measured for the femur and tibia. An average of the right and left sides of the bone pairs was used (when both were present) to give a slightly better reliability (1952:474). This was done by adding or subtracting half the difference between the two sides. Statistical analyses and single and multiple bone regression equations were done for all sample groups. Since the femur and tibia gave nearly identical results when estimating stature, they observed no advantage in using both measurements in multiple equations. The bones of the upper limbs gave higher error rates than those of the lower limbs, and there was no observed increase in accuracy from using the measurements of four bones (humerus, radius, femur and tibia) over the use of only the (maximum length) femur and tibia, which gave the maximum validity of stature estimation (1952:487).

As a way to test their equations, they applied them to a new sample. They utilized 100 "white" male individuals originally considered incomplete due to miscellaneous missing limb bones as a way to validate their equations. They estimated these statures to the nearest centimeter using data measurements from each of the three bones of the arm and leg as well as for the tibia plus femur. They compared the statures they obtained to those in the induction records of the soldiers. Each of the four trials produced comparable results with error rates close to zero.

They also calculated statures on these individuals using the equations for the humerus and femur of previous researchers, finding that those of Manouvrier, Pearson, and Telkka underestimated the statures of the male military subjects while Dupertuis and Hadden's formulae overestimated them (Trotter and Gleser, 1952:505). The researchers also cited the significantly different body proportions of the European Americans and African Americans (the latter having longer limb bones relative to stature than the former) as a way to dismiss Dupertuis and Hadden's idea of "general formulae" that can be applied to both groups.

From these tests, they concluded that their own equations "may be applied without reservation to the entire population of *American White Males*," (Trotter and Gleser, 1952:501, emphasis added) and they expected their equations for the African Americans to prove applicable as well with further testing of validity. My emphasis added to their statement was meant to support their claim for caution when applying their equations to other populations, especially much earlier ones.

Trotter and Gleser conducted another study that was published in 1958. They again utilized data for American military men; however, this time they were individuals who had served in the Korean War between 1950 and 1953. The total sample of 5,517 was divided into five categories of "White," "Negro," "Mongoloid," "Mexican," and "Puerto Rican" based on racial origin and geographic location (1958:81). Only maximum long bone lengths were used, being measured in the same manner as in the previous study. Right and left sides of bones were not averaged this time, but considered separately, and statistical analyses were performed.

Not surprisingly, the results showed once again that sufficient proportional differences existed between three sample populations (the "White," "Negroid" and "Mongoloid" groups) so that the best estimates would be obtained by using population-specific regression equations. The Puerto Ricans and African Americans, although not being of comparable stature (the former group was shorter-statured), did demonstrate approximately equal body proportions such that "the equations for estimation of stature derived from the data of the Negro series are applicable to the Puerto Ricans" (Trotter and Gleser, 1958:121). These findings supported their previous criticism of "general" formulae—that it was better to use equations from a "similar" population than one that averaged results from different populations—by showing that one equation can be applied to two groups with similar body proportions.

FULLY, 1955

A study that examined body proportions and stature --another anatomical study--was undertaken by Georges M. Fully in 1955. His reconstruction method was reminiscent of Dwight's 1894 method with one important (and major) difference. That difference was that the bones did not need to be articulated and held in place with clay for them to be measured. The materials used in his study were corpses of French citizens who had died in Mauthausen, an Austrian concentration camp, and had been buried in an SS cemetery on the premises. Some of the individuals were still in association with an identification plate that had been attached to their wrists by a leather or metal strap (Fully, 1956:266), so their identities could be matched with camp records and confirmed by family members. A total of 3,165 corpses were exhumed from two cemeteries, and most were considered to be in good condition.

To determine the statures, Fully relied on the tables established by Rollet and Manouvrier and a method (unknown to me) established by Borsos Nachtnebel-Schultz. Because the statures of these individuals could be determined from their identification bracelets or military records, Fully was able to examine the reliability of the previous researchers and attempt a new way to estimate living stature from these skeletal remains.

Body proportions also proved to be an important influence on reliability in this study, as the tables established in the 1890's were accurate when the individuals were proportionate, and "inexact or not precise enough" when the "trunk was too long and the limbs too short or vice versa" (Fully, 1956:267). For those individuals with long lower limbs and a short (disproportionate) trunk, the statures were overestimated, and the reverse was true for individuals with a long trunk and short lower limbs. Because these problems existed in the case of body proportions, Fully felt that previous methods could be invalidated as unreliable for the identification of an unknown individual.

Fully wanted to establish a way of estimating stature that reflected all parts of the body that contributed to stature, including not only the bones, but also the soft tissue and spinal curvature. To this end, measurements of bones not previously used in most stature estimations were added. These included the basi-bregmatic height of the skull (BBH), maximum anterior heights of all the vertebrae from C2 to L5, the maximum height of the first sacral vertebra (S1), and the articulated height of the talus and calcaneus (ankle height). These measurements, added to the physiological lengths of the femur and tibia, made up the skeletal height. To this number, Fully added a correction factor to compensate for missing cartilage and intervertebral discs. For skeletal heights up to 153.5 centimeters, 10.0 centimeters were added to the result, 10.5 centimeters for heights between 153.6 and 165.4 centimeters, and 11.5 centimeters to skeletal heights over 165.5 centimeters (Fully, 1956). While Fully acknowledged that certain conditions of aging warranted adjustments to these correction factors, he did not elaborate on ways to correct them, nor did he publish information regarding the ages of individuals in his 1956 study.

Fully's new method resulted in greater accuracy than those of previous researchers. The methods of Rollet and Manouvrier produced errors up to nine centimeters, while Fully's error did not exceed 3.5 centimeters (1956:271). This increase in accuracy was credited to the introduction of the trunk height, considered "absolutely fundamental, if one wants to give a general formula, valid for all races, for both sexes, whether the subject has a long trunk…or short trunk in relation to its stature" (Fully and Pineau, 1960:146).

FULLY AND PINEAU, 1960

A major improvement over the 1894 method of Dwight both in terms of accuracy and practicality, Fully's method was still criticized because it required a nearly complete skeleton, something not always present in archaeological or forensic contexts. In 1960, Fully sought to address this problem and subject the method to statistical analysis by conducting a new study with H. Pineau. For their subjects, they used remains of 164 European males between the ages of 18 and 65, who had died as concentration camp internees (and whose identification could be ascertained from military records).

After determining the percent contribution of each vertebra to the length of the complete spinal column, they developed regression equations such as the ones below that could be used to reconstruct the total length of the spine from an incomplete one:

Height of spine

$=7.12\ (T1 + T2 + T3) + 139$ mm

$=6.53\ (T5 + T6 + T7) + 103.4$ mm

$=5.59\ (T10 + T11 + T12) + 88.55$ mm

$$=3.205\ (T5 + T6 + T7 + L1 + L2 + L3) + 34.8\ \text{mm}$$

$$=2.87\ (T10 + T11 + T12 + L1 + L2 + L3) + 47.5\ \text{mm}$$

(Fully and Pineau, 1960:150)

In cases where preservation was especially poor and few vertebrae were present, one could utilize regression equations that incorporated either the femur and tibia and a portion of the spinal column (for example, Stature= 2.32 (Tibia + 5 Lumbar) + 48.63). And if the lumbar vertebrae were also missing, their values could be found by using a table the authors had set up for that purpose. These long bone and partial spinal equations were found to have a correlation coefficient (r) of 0.926, and were considered general enough to use for subjects of various ethnic backgrounds (Fully and Pineau, 1960:152).

GENOVES, 1967

Despite the improvements brought about by Fully and Pineau, the anatomical method did not immediately change the way that stature studies were done. It is possible that both the 1956 and 1960 studies, having been published in the French journal "Annales de Medecine Legale" were not well-known or widely available to researchers in other parts of the world. This may have been the case for Santiago Genoves who, also concerned about the effect of proportionality on stature formulae, published findings of his own study in 1967.

Citing a previous study he had conducted in 1958, Genoves supported the conclusion of previous researchers that "we need to be sure that the racial affiliation of the sample is the same as that of the population or of the individual to whom we apply such formulae" (Genoves, 1967:67). When he attempted to calculate the stature of prehistoric Mexicans using formulae derived from a British population, both male and female Mesoamerican stature was greatly overestimated at 189.2 and 199.8 centimeters respectively, even though the same formulae were adequate for recent Belgian individuals. The formulae derived by Trotter and Gleser in 1958 on Mexican soldiers of the Korean War also produced statures above the Mesoamerican male norm.

Genoves arrived at a sample size of 98 (69 male and 29 female) cadavers for use in his study. The individuals were arranged into seven groups ranging from "indigenous" to "white" based on morphological characteristics and ABO blood groups. Many of the original set of 235 were discarded because they lacked known stature, "congruent morphoscopic and serologic characteristics" or *any* of six long bones (Genoves, 1967:70). In this way, the sample was made more homogeneous. He measured the maximum lengths of the femur, tibia, fibula, humerus, radius, and ulna for each individual. Routine statistical analyses of his data were performed by computer, regression equations were calculated using the femur and tibia (as these bones had the highest correlation to stature), and tables were created for estimating stature from all six of the long bones. Genoves obtained stature results lower than those of any other researcher; however, statures derived from both male and female skeletal materials were remarkably close to those obtained on *living* Mexican subjects by Hanna Faulhaber in 1964 and 1965. A personal communication cited in his 1967 paper revealed that his equations also worked quite well in estimating the statures of Native American skeletons from Arizona and New Mexico. While Genoves declined to draw conclusions with regard to the applicability of his formulae to those other populations, he did infer that it was due to similar proportionality in all the populations.

LUNDY, 1985 AND 1988

John K. Lundy (1985) can be credited for revitalizing interest in the anatomical method that Fully had developed nearly 30 years earlier by conducting a study comparing the anatomical and mathematical methods. Like Fully before him, he also encouraged the use of the anatomical method when skeletal remains are sufficiently complete. However, in cases of incomplete remains, he recommended using the equations of Trotter and Gleser's 1952 study, despite the fact that Fully himself had outlined other ways to estimate stature in those cases and the fact that other researchers (such as Genoves in 1967) had found high error rates with the Trotter and Gleser equations.

Lundy conducted his own case study in 1988, both as a way to test the anatomical versus the mathematical methods and also to advocate the use of Fully's method whose "use seems rare among forensic anthropologists" (Lundy, 1988:534). His sample consisted of only three individuals, all American male Vietnam War servicemen. These remains were virtually complete, and were therefore able to be used for anatomical stature reconstruction. While there are disagreements over the degree of accuracy of recorded living statures (see Snow and Williams, 1971), Lundy's anatomical stature results most closely matched those previously recorded in military records.

The statures obtained from Fully's anatomical method and Trotter and Gleser's regression equations for American "white" males were compared to the recorded antemortem stature, in inches, below (Lundy, 1988:537):

Case	Recorded	Fully	Trotter and Gleser
A	70.5	70.6	68.4 (67.22-69.58 range)
B	69.5	69.9	68.6 (67.42-69.78 range)
C	71.0	70.2	71.3 (70.12-72.48 range)

Lundy demonstrated that in all three cases, both the mathematical and anatomical methods worked equally well, with the anatomical method producing the most accurate result in Case A. It is not surprising that the Trotter and Gleser equations in this case produced accurate estimations, as they were originally calculated to estimate statures of American "white" males, such as the ones in Lundy's study.

SCIULLI ET AL., 1990

Paul Sciulli, Kim Schneider, and Michael Mahaney utilized the Fully anatomical method in their 1990 study of prehistoric Ohio Native Americans. This method was chosen because of its accuracy in estimating statures of individuals of unknown living stature (as is the case for most archaeological remains). The study sample consisted of 64 individuals, 35 male and 29 female, from populations that lived from 3,000 to 400 years BP. They were a rather young group, with the females averaging 34.5 (+/- 8.6) years old and the males averaging 35.8 (+/- 7.9). Of these 64, 55 were sufficiently complete to utilize the Fully method in calculating their statures. The other nine contained a total of 12 vertebrae that were either missing or damaged. The heights of these vertebrae were estimated by averaging the heights of the vertebrae directly above and below them. According to Sciulli et al. (1990:276), this was "virtually identical to estimating the heights from the percentage contribution of each vertebra to the vertebral column height" and was a less complicated procedure. They were age-corrected using the factor (set forth by Trotter and Gleser, 1952) of .06 centimeters reduction for every year over the age of 30.

Regression equations were developed on the *uncorrected* skeletal height for males and females separately and together on the maximum femur length, bicondylar femur length, tibia length, bicondylar femur plus tibia length, bicondylar femur plus tibia length plus lumbar vertebrae, and vertebral column height. The regression equations were used to calculate the skeletal heights of the Native Ohio individuals, which were then converted to living stature by adding the soft tissue correction factor and subtracting the age correction (Sciulli et al. 1990:277). The researchers then examined regression equations developed on other populations and commonly recommended for use on Native American populations. These included Trotter and Gleser's (1958) equations for Mexican males and "Mongoloid" males, Genoves' (1967) Mesoamerican equations for males and females, and Neumann and Waldman's (1968) equations for prehistoric Middle Mississippian males and females.

The results of this study demonstrated (once again) that equations developed on one population--even one considered to be similar in origin--may not produce accurate results when applied to another. In this case, formulae from all the other studies overestimated the statures of the prehistoric Ohio Native Americans by between two and eight centimeters. The fact that the Middle Mississippian estimates were also too high prompted Sciulli et al. (1990:279) to state that their own regressions would not be "generally applicable to all Eastern Woodland Native Americans…but should provide good stature estimates in populations with approximately the same proportion of skeletal height contributed by the [body] components."

FELDESMAN ET AL., 1988-1990

Stature studies shifted focus somewhat by researchers interested in determining the body size (and weight) of fossil hominids. As body size is highly correlated to stature, the issue became how to determine living statures for people with no counterpart among extant populations. Virtually all regression equations for modern populations proved inaccurate to calculate Australopithecine height. In fact, T. Geissman (in

Feldesman and Lundy, 1988:584) cited the overestimation of "Lucy's" anatomically reconstructed stature by 45 separate regression equations! The problems involved in reconstructing the stature of these hominids using modern regression equations can be partially attributed to disagreements by anthropologists regarding Australopithecine proportionality. Without having an adequate understanding of the relationship between stature, trunk, leg, and (to a lesser degree) arm length, it would be difficult to determine which population's equations would be "similar" enough to use. Additionally, it is possible that the statures of the early hominids calculated from modern regression equations were still overestimated by one to two centimeters due to their smaller cranial capacities (reducing the basi-bregmatic height)(Feldesman and Lundy, 1988:589).

Despite the difficulties mentioned above, Feldesman et al. (1990:360) noted that researchers continued to "appl(y) with abandon the forensic equations Trotter and Gleser…devised for entirely different purposes." To try to address the problem, they rediscovered an alternative--and as it turned out, easier--method to estimate living statures. This method was the femur/stature ratio, a measurement often calculated in the past, but virtually abandoned after Pearson's introduction of the regression equation in the late 19th century. The femur/stature ratio is a gender-and-ethnicity-independent ratio defined as the maximum femur length (in cm) * 100/living stature (Feldesman et al. 1990:360).

Feldesman and Lundy calculated the femur/stature ratio of 13 modern populations originally as a way to support or refute their past conclusions regarding the body proportions of the Australopithecine "Lucy." Since the average of these 13 populations was 26.7% with a very small standard deviation (0.55), the researchers decided to examine this ratio more closely. They found data for a total of 51 varied populations (with a sample size of over 13,000 individuals) for which they were able to calculate the femur/stature ratio. The average ratio value for all these populations was 26.74%, varying only slightly from their past research, suggesting that it might be possible to use this ratio as a way to calculate statures for unknown individuals regardless of sex or ethnicity. As there were differences in the group-specific ratios, Feldesman et al. wanted to test their new general equation (living stature (cm) = maximum femur length X 100/26.74) to see how well it could be applied across ethnic and geographical boundaries.

The first testing sample consisted of 50 "white" males from the U.S. Army Central Identification Center in Fort Schaeffer, Hawaii. In this test, statures were calculated using the femur/stature ratio and the equations of Trotter and Gleser. Even though both results were "significantly different" from the recorded stature, the femur/stature ratio performed slightly better than the regression equations, with standard deviations of 3.06 centimeters and 3.66 centimeters respectively (Feldesman et al., 1990:364).

For their second test, they randomly selected 32 individuals from a tribal South African population for which they had previously calculated regression equations. The reconstructed statures using the regressions and the femur/stature ratio were compared. Not surprisingly, the error rate (3.4 cm) for the femur/stature ratio calculations was much higher than the 2.15 cm of the regression equations that were calculated specifically for those individuals.

Finally, they estimated the stature of one female Akka pygmy using three techniques: the femur/stature ratio, Trotter and Gleser's equations for "black" females, and their own equations for South African tribal females. They calculated her living stature to be 123.0 centimeters (using the Fully anatomical method). When they viewed the results, it was the femur/stature ratio (at 124.9 cm) that most accurately estimated the stature than either set of regression equations (which resulted in statures of 129.9 cm and 135.9 cm). The Trotter and Gleser equations--typically used as "fallbacks" when other equations are unavailable--most overestimated the stature of this individual.

An analysis of the results of all these tests prompted the researchers to conclude that the femur/stature ratio "typically performs better than Trotter and Gleser's equations on the very populations for which [they] were designed…[and] in the worst of…tests yields results only marginally poorer than those from equations specifically designed for the target population" (Feldesman et al., 1990:366) with the further advantage of not requiring different equations either for sex or ethnicity.

SJOVOLD, 1990

Aware of the difficulties arising from the cross-application of stature regression equations between populations with different body proportions, T. Sjovold (1990) also attempted to create "generic" formulae that would be applicable to all human populations without regard to sex or ethnicity. Somewhat reminiscent of Rollet's 1888 study, Sjovold wanted his method to reflect "bilaterality," stating, "it is fair to state that stature may be explained by the length of a bone, but the bone length may in the same manner be explained because of the stature" (1990: 433). Sjovold felt that this bilaterality could be accomplished not by the use of unilateral regression equations, but by the use of his own method which he called the "line of organic correlation" (1990: 436).

He conducted a study using over 10,000 individuals from various "races" and calculated nine formulae using single bones only, including both the maximum and physiological lengths of the radius, femur and tibia. *Weighted* correlations between mean bone length and mean stature ranged from as low as 0.5839 for the physiological length of the tibia to 0.9530 (the highest) for the maximum length of the femur.

A researcher named Formicola, attempting to calculate statures for extinct hominids tested the Sjovold "line of organic correlation" and the femur/stature ratio of Feldesman et al. (1990). He found that both methods resulted in "credible" statures for individuals who were short or medium-statured, but still overestimated stature for tall individuals (in Feldesman and Fountain, 1996: 208).

RUFF AND WALKER, 1993

Like Feldesman and Lundy (1988) before them, Christopher Ruff and Alan Walker (1993) attempted to estimate the body size and shape of an early hominid. This time it was the 1.5 million year old male *Homo erectus* (KNM-WT 15000) from Nariokotome, Kenya. Ruff and Walker, in order to obtain an accurate estimation of this hominid, first needed to correctly determine his body proportions. The completeness of the remains--rare in skeletons of this age--provided the researchers a unique opportunity to accomplish their goal.

They reasoned that an examination of the *inter*-limb proportionality (that is, the distal/proximal bone lengths of the upper and lower limbs) would indicate which reference population should be used to produce the most accurate estimation of stature and body weight. The brachial (radius/humerus length) and crural (tibia/femur length) indices placed KNM-WT 15000 above the reference populations of living Africans and Europeans; however, Ruff and Walker concluded that he "group(ed) strongly with modern tropical populations…based *not* on proposed "racial" or "ethnic" affiliation *per se* but, rather on basic thermoregulatory principles that should be universally applicable" (Ruff and Walker, 1993: 243). For this "hyper-tropical" hominid, Ruff and Walker believed that the best reference populations for stature estimation would be the South African Bantu (studied by Feldesman and Lundy in 1988) and four Ugandan samples (from Allbrook, 1961).

Complicating the stature estimation was the fact that the Nariokotome individual was a juvenile whose age at death was determined to be between 11 and 12 years based on dental eruption and the stage of ossification in the epiphyses of the humerus. His stature at death using regression equations from the reference populations was calculated to be an average of 160 centimeters. To determine how tall he would have been had he lived to maturity, Ruff and Walker extrapolated the length of his long bones based on the average percent change in long bone lengths expected for boys between the ages of 12 and 18. The projected adult stature of KNM-WT 15000 was recalculated and found to "cluster" around 185 centimeters using six different bone measurements (maximum and bicondylar femur, tibia, and ulna).

As both the Trotter and Gleser formulae and the femur/stature ratio overestimated the stature of this juvenile by between two and eight centimeters (and were inappropriate for his body type), Ruff and Walker (1993: 262) concluded, "the body shape of KNM-WT 15000 indicates that only tropically proportioned modern reference samples should be used in reconstructing his stature and body weight."

This review of previous researchers' work adequately demonstrates the complexity of stature reconstruction over the last century. How well would the equations and conclusions of those before me stand up to my own examination? Using the insight and contributions of researchers over approximately the last fifty years, I explored for myself which methods resulted in the most reliable estimates of stature for the Native Americans in my study.

MATERIALS AND METHODS

All of the skeletal materials used in this study came from collections housed at the Smithsonian Institution's National Museum of Natural History in Washington, D.C. All of the data was collected over a four month period in the fall of 2000. The groups represented here include 20th century Americans of European and African descent from the Terry Anatomical Collection, late prehistoric Native Americans from the Aleutian Islands, protohistoric Native American Arikara from South Dakota, and Native Americans from southwest Alaska (time period undetermined).

TERRY ANATOMICAL COLLECTION SAMPLE

The Terry Anatomical Collection consists of skeletal remains of over 1,700 individuals, collected by Robert J. Terry from the 1920's until his retirement in 1941 when charge of the collection was taken over by Mildred Trotter (until her own retirement in 1967). The earliest individuals were those who had been unclaimed by relatives or signed over to the state for study. Subsequent changes to the law--specifically the Willed Body Law of 1955-1956--required written permission for bodies to be used for scientific purposes, and the later-willed individuals came from the middle and upper income group (Hunt, 2000:2).

The cadavers from the collection were originally prepared by students at the Washington University Medical School in St. Louis, Missouri, under specific guidelines established by Terry. Because Terry had not allowed students to remove all the fat from the bones, they remained in an excellent state of preservation (although years of study have caused some subsequent damage). Many of the crania had been sectioned during preparation; in some individuals, the calvarium alone had been cut, others had been cut sagitally as well.

Each individual has a morgue record on file at the museum which documents (among other things) age at death and ethnicity, and skeletal inventories that list bones that were missing or damaged during preparation. Many of the files also contain cadaver statures measured on the individual before preparation. These statures were not measured on a flat table; instead, a special type of table was created that allowed the individual to be measured and photographed in as natural a standing posture as possible. The feet of the cadaver were placed against a footboard and straps were attached to hold the body in place on the table. Part of the table was then tipped forward and the body assumed a natural position: the lumbar curvature present, shoulders in position, ankles bent, knees and hips extended, and head supports kept the head in correct Frankfurt plane for anthropometric measurement (Terry, 1940:438).

This collection represents individuals who died between the ages of 16 and 102 (and who were born between 1822 and 1943). The majority of the individuals were over the age of 45 at the time of death, and the demographics of the collection are as follows (Hunt, 2000:3):

"White" males	461
"Black" males	546
"White" females	323
"Black" females	392
Asiatic males	5
Unknown origin	1

For all the individuals in this collection, sex and age were well documented, and I found them by referencing the morgue records on file. For my study, 217 individuals were measured, consisting of 109 females (58 of African descent and 51 of European descent) and 108 males (54 of each group).

ALEUTIAN SAMPLE

The Aleutian sample consists of 37 individuals (21 males and 16 females) from the eastern Aleutian Islands of Kagamil and Umnak. The skeletal material from

Kagamil, one of seven islands that make up the Islands of the Four Mountains, came from a burial cave. There are 18 individuals from Kagamil represented in this study (9 males and 9 females), three between the ages of 20 and 34 at the time of death, 12 between 35 and 49 years old, and the rest were estimated to have been over the age of 50.

The cave in which the Kagamil materials were found provided excellent conditions for preservation. These conditions not only contributed to the preservation of skeletal material, but also wooden artifacts, clothing, basketry, and other vegetable products (McCartney, 1984:131). Many of the individual bones, including the vertebrae, were still articulated and held in place by desiccated connective tissue at the time of study. Because of the nature of the artifacts, and folklore accounts of Kagamil burials, these mummified remains could be dated to the late prehistoric period (McCartney, 1984).

Reports about the archaeological investigations on Umnak Island indicate that human occupation was more or less continuous from 2500 B.C. to the present in sites in the southwestern end of the island. The only site excavated (by 1984) in the northeastern end of the Island (Ashishik Point) dates occupation there to between only A.D. 200 and the late prehistoric period

(McCartney, 1984). Without knowing where on the island these remains came from, I cannot be certain of the time period they represent, and they conceivably could come from any time within the more than 4,000 years that the island was occupied. In any case, there are 19 individuals represented (seven females and 12 males) in this study. I estimated three of the individuals to be between 20 and 34 years old at the time of death, two to be between 35 and 49 years old, and the majority (11) to be age 50 or older.

ARIKARA SAMPLE

The Arikara sample is made up of remains of individuals from various sites in South Dakota, including Sully (39SL4), Cheyenne River (39ST1), Mobridge (39WW1), and Rygh (39CA4). The sample contains 63 individuals, 33 female and 30 male, and ages range from very early adulthood (15 to 19 years old) to 60 years of age (age and sex determined by museum staff prior to my study). The younger individuals were included to make up a larger sample size; however, they were all considered adult (that is, none was included unless long bone epiphyses were at least partially fused).

These northern plains Natives have been studied since the late 1800's, but have received the greatest amount of attention in only the last 50 years (see Bass, 1964; Hurt, 1969; Jantz, 1970; and Owlsey and Jantz, 1994). The Arikara are the most northern of the Caddoan-speaking people believed to have migrated northward during the later part of the Plains Village period (A.D. 950-A.D.1700) of the Plains chronology (Blakeslee, 1994:23). The Arikara in this study are considered protohistoric and likely date to between A.D. 1600 and 1750. (Bass, 1964:72).

ALASKAN SAMPLE

My Alaskan sample consists of 98 individuals (48 females and 50 males). Almost half of the sample (44 individuals) was estimated to be between the ages of 20 and 34 years old, 23 were between the ages of 35 and 49, and the rest over the age of 50 at the time of death.

While I had very little information regarding these people, I did have information on the quadrants of Alaska in which they were found. With no idea of the time period represented by these individuals or their cultural affiliations, I decided to treat them as a geographical unit and restricted the sample to the southwestern portion of Alaska. It is quite likely that small groups in this region would have interacted with each other, encountered similar environmental (climatic) stressors and even intermarried, exchanging genetic material.

ESTIMATING AGE AT DEATH

Most of the Alaskan individuals had not been formally aged at the time of my study, so determining their ages at death became part of my data collection procedure. My determinations of age, based on a combination of dental eruption, tooth wear, epiphyseal closure, pubic symphysis appearance, and certain age-related pathologies were made in the following manner.

First, I examined the skulls for dental eruption. Teeth erupt in a more or less well-known sequence, and whether or not they were all present, the existing molars were examined for the amount of wear (loss of surface due to abrasion) exhibited in each. If, for example, the third molars were not present (either congenitally absent, lost post-mortem, or non-erupted) but the M1 and M2 (1st and 2nd molars) showed extreme wear, I could assume that a great deal of time had elapsed for that degree of wear to have occurred.

Next, I examined the long bones of the arms and legs for epiphyseal closure. As a person ages, the ends, or epiphyses, of the long bones begin to fuse to the shafts. The rate of this fusion is different for each bone and may vary between individuals as well, although average age ranges for epiphyseal closure have been established (see Bass, 1971; Krogman, 1973). Using the tables of McKern and Stewart (1957), I rated the amount of epiphyseal closure from zero (no union) to four (completely fused), and used the tables they established for age of closure to estimate age.

I then examined the surface of the pubic symphyses (when they were present). This is considered to be one of the best locations for determining a person's age. The surface of the symphyseal face of the pubis goes through certain morphological changes after about the age of 18. These changes were broken down into a series of phases with descriptions and illustrations of the changes that can be expected during each phase for males (Todd, 1920) and for females (Brooks and Suchey, 1990).

Lastly, I examined the vertebrae for evidence of pathology, specifically osteophytic lipping and degenerative changes that begin to appear in the spine after the mid-twenties. These have also been assigned values from zero to four, each corresponding to an age range (Stewart, 1958). This particular factor may have caused me to over-estimate the ages of some individuals with marked changes to the vertebrae, as I was unsure of the degree to which the daily activities of the population may have contributed to the formation of osteoarthritic changes. This was especially true after I re-examined the Alaskan individuals with the most severe changes such as vertebral compression and compression fractures. The youngest of these had been estimated (by someone else) not to have been older than mid-thirties at the time of death.

CONDITIONS OF INCLUSION INTO STUDY SAMPLE

Once sex and age determinations had been made, I examined each skeleton for completeness. For the Terry collection and many of the Arikara individuals, the vertebrae had been placed in their correct order (C1-L5) and strung together. For individuals from the other collections, I had to first articulate the spinal column, sometimes having only the vertebral centra lacking the articular surfaces of the transverse processes. I excluded from the study any individuals missing the C2 vertebra, more than two consecutive vertebrae, or more than three vertebrae from the entire spine. Also, each individual had to have a skull from which the basi-bregmatic height could be measured, and both long bones of the leg. I did not exclude those individuals who lacked the calcaneus or talus, as the ankle height did not appear to be very variable within a population and could be determined without direct bone measurements (by using the mean value of the ankle heights of the same sex within the population). However, this conclusion was based on my own observations, as I have not found any literature dealing with this particular trait.

METHODS OF BONE MEASUREMENT

I measured the basi-bregmatic height (BBH) of all the skeletons using spreading calipers. The BBH is measured from bregma, the point at the top of the skull where the coronal suture meets the intersection of the sagittal sutures, to basion, the midpoint of the cranium anterior to the foramen magnum (Bass, 1974:59). Many of the skulls in the Terry collection had been sectioned during preparation; some cut around the calvarium, others cut sagitally as well. In all those cases, I held the pieces together with small pieces of masking tape so I could measure the skull height accurately.

Next, I measured the height of each vertebra (in order) from C2 to L5. Measuring the C2 incorporates the height of the C1 (or atlas vertebra), so this does not have to be measured separately. Using a digital caliper, I measured the C2 vertebra from the most superior point of the odontoid process to the most inferior point of the anterior margin of the body. For vertebrae C3 through L5, I measured the maximum anterior height, holding each vertebra with the anterior side facing up and the spinous process to the left (these measurements are illustrated in Lundy, 1988:535). I measured the anterior height of S1, the first sacral vertebra, with a sliding caliper from the center of the promontory to the most inferior point of the vertebral body.

I measured the long bones of the legs of all the Native American individuals (the long bones from the Terry Collection individuals had been measured and recorded by previous researchers at the Smithsonian) using an osteometric board. I measured the physiological length of the femur by resting the condyles against the stationary end of the board and applying the moveable end to the head of the femur (Bass, 1971:168). I also measured the maximum length by placing the condyles against the stationary end of the board and the moveable end against the opposite end of the bone, moving the bone from side to side until the maximum length was found. I measured the maximum length of the tibia on an osteometric board by placing the intercondyloid eminence (or tibial spines) inside the hole in the fixed end of the board and the median and lateral condyles of the superior end of the bone against the board. With the long axis of the bone parallel to the osteometric board, I brought the moveable end of the board down onto the medial malleolus and measured the maximum length.

I also measured the maximum lengths of the three long bones of the arm. I placed the humerus on the osteometric board with the head against the stationary end and brought the moveable end of the board down onto the distal end, moving the bone in all directions until I found its maximum length. I measured the ulna in the same manner as the humerus, from the top of the olecranon to the tip of the styloid process. For the radius, I measured maximum length from the head to the tip of the styloid process.

To obtain the ankle height, I articulated the calcaneus and talus and held them in anatomical position while placing the calcaneus against the stationary end of an osteometric board. Reconstructing the arch of the foot, I raised the calcaneus and brought the moveable end of the board onto the talus (illustrated in Lundy, 1988:537). As the ankle height could vary from both intra- and inter-observer error (as I discovered from personal experience), it could potentially have an effect on the final stature; however, this effect would be minimal.

CORRECTIONS FOR AGING ON STATURE

Most of the researchers before me had made corrections for aging on stature for the individuals in their study sample. I did not utilize any of the "correction factors" previously used because of the large ranges for each age category (for example, 35-49).

These correction factors stipulate that a certain amount of stature be deducted for each year after the age of thirty. Without a way to narrow the age range (as well as the confidence level of the age estimate), the only corrections I made for "aging" were for those individuals in whom I had noted severe vertebral pathologies--specifically vertebral compression fractures which can considerably reduce the anterior height of the vertebrae.

These fractures, while typically seen in the elderly with cases of bone-weakening osteoporosis, can also be found in younger individuals and are a reflection of overall bone health. In modern populations, they have been associated with osteoporosis caused by endocrine disorders, digestive diseases, bone marrow diseases, specific medications, or no known underlying cause at all(idiopathic) (Watts, 2001:2). It is difficult to know with certainty the causes in prehistoric populations. In a study such as this one, it was important to correct for this pathology because I needed to recreate the maximum stature for these individuals to calculate the most accurate regression equations possible. In this study, I corrected the statures of four Alaskan individuals by seven, 13, 22, and 26 millimeters by using the method advocated by Sciulli et al. (1990) for estimating missing or damaged vertebrae (averaging the heights of the vertebrae directly above and below them).

All of the actual bone measurements (*not* the corrected measurements which were made after closer examination of the data), rounded to the nearest millimeter, were entered into the Smithsonian database, and a disc copy was given to me at the end of an internship with the museum. The file was transferred to Paradox on the campus of Oregon State University, which I used to sort the data by population and sex. The sorted files were then imported to the Systat computer program which I used to calculate all of the stature estimations, run statistical analyses, and formulate regression equations.

RESULTS AND DISCUSSION

Because the formation of regression equations was one of the goals of my thesis, I first needed to get an accurate estimation of living stature for all of the groups in my study. This brought me back to my first and most basic research question--how to most accurately reconstruct living statures for individuals with no medical or military records to consult.

Table 1, below, shows the results of calculations of stature for the Terry Anatomical Collection individuals using two methods, the Fully anatomical method and the femur/stature ratio. This sample was chosen as a test because these individuals had cadaver lengths on file which could be converted into the best estimate of "living stature" from which to compare the stature estimates of the other two methods. This was done by subtracting 2.5 centimeters from the cadaver length (per Trotter and Gleser, 1952).

The differences between the "living statures" and the statures estimated by the Fully anatomical method ranged from -9.00 centimeters to +7.10 centimeters, with an average difference of -1.36 centimeters. Those resulting from the femur/stature ratio ranged from -8.33 to +17.5 centimeters, with an average difference of +4.26 centimeters. I was expecting smaller differences with the Fully anatomical method, and reviewing the measurements of the individual bones did not provide an explanation for the discrepancies observed; however, there were several possible explanations.

TABLE ONE

TEST OF RECONSTRUCTION ACCURACY

Males and Females of the Terry Anatomical Collection
(Means and Standard Deviations in cm)

		Liv stat	Fully Est	F/S Ratio
African Females	(58)	**157.1**	**156.8**	**165.4**
		6.80	6.86	8.87
African Males	(54)	**167.7**	**166.6**	**175.2**
		6.78	6.01	9.53
European Females	(51)	**156.6**	**156.0**	**159.6**
		7.17	5.74	8.19
European Males	(54)	**168.2**	**165.6**	**170.3**
		4.70	5.91	8.96

Errors in bone measurements, especially of bones in the legs, may contribute to this problem to a large degree. As I stated earlier, there seemed to be a high degree of inter- and intra-observer error with ankle measurements; however, the ankle's contribution to total stature is slight, and even a discrepancy of 10 millimeters would only affect the final stature by one centimeter. One variable that must be addressed is the cadaver length itself, as these were measurements taken by medical students whose technical expertise was unknown. Adding to the possible problem of lack of experience was the measuring technique itself which attempted to reconstruct standing posture including spinal curvature, hip flexure, and foot arch. It might be difficult to account for scoliosis, lordosis, or even flat feet.

Overall, however, the Fully anatomical method still produced results most closely correlated to living stature with a correlation of 0.935, as opposed to the 0.883 for the femur/stature ratio. Because of this, and because the results of this study depend upon being able to accurately reconstruct statures, I considered the anatomically estimated results that I calculated on the Native American populations within this study to be equivalent to their living statures.

Satisfied that I was able to estimate living statures with a high degree of accuracy, I calculated the statures for the three Native American groups in my study. The results can be seen in **Table 2**. From these stature reconstructions, I calculated population-specific regression equations for both sexes. Using these equations, I recalculated the statures of each group and found their means to be virtually identical

TABLE TWO

NATIVE AMERICAN STATURES

(Means and Standard Deviations in cm)

Alaskan Females	(48)	144.81	4.86
Aleutian Females	(16)	144.78	3.89
Arikara Females	(33)	153.59	4.46
Alaskan Males	(50)	152.12	5.83
Aleutian Males	(21)	153.07	3.70
Arikara Males	(30)	165.22	5.07

to the estimates using the Fully anatomical method (not surprising because the formulae had been calculated from the same sample). However, it seemed that there was also a high correlation to living stature across the groups; that is, the equation of one population appeared to work well for another. Because of this, I pooled the samples and calculated regression formulae for each sex using all the individuals in my study. All the formulae can be seen in **Table 3**. (For these formulae, "femur" is always the bicondylar length, "tibia" is the maximum length without the spines, "hum" is the maximum length of the humerus, and "LV" and "Lumbar vertebrae" are the sum of the heights of L1 through L5. For individuals with an extra lumbar vertebra, the additional vertebral height should be added to the resulting stature estimate.)

TABLE 3

REGRESSION EQUATIONS

	Std. Error Of Estimate
Pooled Female Sample: 97	
1. 43.826 + (1.155 Femur) + (1.146 Tibia) + (1.688 LV)	1.575
2. 55.421 + (0.717 Femur) + (1.828 Tibia) + (0.159 Hum)	2.004
3. 56.273 + (1.844 Tibia) + (0.797 Femur)	1.996
4. 70.235 + (2.389 Tibia)	2.170
5. 41.560 + (2.674 Femur)	3.172
Pooled Male Sample: 101	
1. 37.016 + (1.227 Femur) + (1.107 Tibia) + (2.307 LV)	1.650
2. 42.881 + (1.079 Femur) + (1.855 Tibia) + (0.104 Hum)	2.509
3. 42.775 + (1.161 Femur) + (1.849 Tibia)	2.505
4. 64.438 + (2.655 Tibia)	2.790
5. 20.153 + (3.190 Femur)	3.538
Alaskan Females: 48	
1. 42.173 + (2.049 Femur) + (1.897 Lumbar vertebrae)	2.090
2. 50.149 + (0.753 Femur) + (1.909 Tibia) + (0.192 Hum)	1.986
3. 51.171 + (1.942 Tibia) + (0.840 Femur)	1.968
4. 57.467 + (2.798 Tibia)	2.100
5. 55.746 + (2.265 Femur)	2.486
Alaskan Males: 50	
1. 31.311 + (2.144 Femur) + (2.636 Lumbar vertebrae)	2.104
2. 48.586 + (0.792 Femur) + (1.276 Tibia) + (0.912 Hum)	2.614
3. 49.109 + (1.272 Femur) + (1.496 Tibia)	2.655
4. 43.721 + (2.583 Femur)	3.087
5. 68.218 + (2.529 Tibia)	2.943
Aleutian Females: 16	
1. 30.596 + (2.001 Femur) + (2.951 Lumbar vertebrae)	1.189
2. 62.485 + (1.155 Femur) + (1.007 Tibia) + (0.250 Hum)	2.039
3. 63.606 + (1.075 Tibia) + (1.252 Femur)	1.970
4. 72.000 + (2.357 Tibia)	2.247
5. 68.797 + (1.984 Femur)	2.077
Aleutian Males: 21	
1. 60.965 + (1.875 Femur) + (1.161 Lumbar vertebrae)	1.303
2. 58.803 + (1.633 Femur) + (0.615 Tibia) + (0.200 Hum)	1.460
3. 58.270 + (0.673 Tibia) + (1.745 Femur)	1.426
4. 70.407 + (2.495 Tibia)	2.233
5. 63.921 + (2.146 Femur)	1.479
Arikara Females: 33	
1. 38.362 + (1.606 Femur) + (3.723 Lumbar vertebrae)	1.764
2. 54.331 + (0.780 Femur) + (1.590 Tibia) + (0.390 Hum)	1.998
3. 55.207 + (1.749 Tibia) + (0.904 Femur)	1.989
4. 66.021 + (2.498 Tibia)	2.112
5. 56.286 + (2.373 Femur)	2.495
Arikara Males: 30	
1. 34.217 + (2.132 Femur) + (2.631 Lumbar vertebrae)	1.845
2. 39.900 + (1.775 Femur) + (0.718 Tibia) + (0.592 Hum)	2.335
3. 48.067 + (0.720 Tibia) + (2.016 Femur)	2.344
4. 59.703 + (2.784 Tibia)	2.916
5. 51.622 + (2.548 Femur)	2.365

TABLE 4

TEST OF REGRESSION EQUATIONS

(Statures in cm)

Individual	"Living" Stature	Population-Specific Eq.	Pooled Sample Eq.
A: Arikara Female	150.50	151.79	151.78
Age 20-34		151.53	151.61
B: Arikara Female	158.60	158.53	158.74
Age 20-34		158.36	158.27
C: Arikara Male	166.60	166.43	166.16
Age 35-49		167.64	166.72
D: Arikara Male	163.10	162.60	162.98
Age 35-49		164.59	164.10
E: Alaskan Female	145.40	144.86	146.20
Age 35-49		146.94	147.18
F: Alaskan Female	148.80	150.93	150.39
Age 35-49		149.81	149.91
G: Alaskan Male	151.40	149.82	149.81
Age 50+		148.22	148.66
H: Alaskan Male	164.40	159.88	160.43
Age 35-49		159.69	161.12
I: Aleutian Female	144.60	142.68	143.11
Age 20-34		146.44	145.42
J: Aleutian Female	155.80	152.33	154.24
Age 50+		154.53	154.97
K: Aleutian Male	159.80	159.29	161.77
Age 50+		161.24	163.26
L: Aleutian Male	150.60	151.98	152.11
Age 20-34		151.47	150.61

Table 4 (preceding page) illustrates the results of a test of my population-specific and pooled regression equations. For this test, I chose 12 individuals (two for each sex of each population) from my original sample who had **not** originally been used in my study sample (and the calculation of the subsequent regression equations). I calculated the stature of each individual using the Fully anatomical method to obtain the best estimate of "living stature," and then compared the statures I obtained using the 1ST and 3rd equations from each group in Table 3. The results clearly illustrate that both the population-specific and the pooled sample equations worked well for each of the random individuals I had selected.

Because part of the difficulty in using regression equations to estimate statures for unknown individuals arises from their inability to be used across populations, I applied some regression formulae of other researchers to my own sample populations to evaluate their applicability.

I utilized the following equations, chosen because they had either been formulated on native groups, had been found applicable to some native groups, or had been used extensively to try to estimate living statures:

Sciulli et al., 1990, Ohio Native Americans**

Male: 1.40(Femur+Tibia) + 37.48 (± 2.90)

Female: 1.68(Femur+Tibia) + 13.63 (± 2.34)

(**for *uncorrected* skeletal heights)

Genoves, 1967, Mesoamericans

Male: 1.96 Tibia + 93.752 (± 2.812)

Female: 2.72 Tibia + 63.781 (± 3.513)

Trotter and Gleser, 1952, "White" Americans

Male: 1.30(Femur+Tibia)+ 63.29 (± 2.99)

Female: 1.39(Femur+Tibia) + 53.20 (± 3.55)

Trotter and Gleser, 1958, "White" Americans

Male: 1.26(Femur+Tibia) + 67.09 (± 3.74)

Trotter and Gleser, 1958, "Mongoloid"

Male: 1.22(Femur+Tibia) + 70.37 (± 3.24)

Sjovold, 1990, Line of Organic Correlation

All: 2.71 (Maximum Femur) + 45.86 (± 4.49)

Table 5 shows the mean stature estimates and standard deviations from my own *pooled* equations and those of researchers listed above. Pearson's correlations (**Table 6**) illustrate that my own regression equations still produced the most accurate mean stature results with those of Sciulli et al. (1990) producing the second best results in five out of six cases (although it also consistently underestimated the statures), followed very closely by the equations of

Trotter and Gleser. In the case of the Aleutian males, the "generic" equations (the femur/stature ratio and the line of organic correlation) which performed so poorly for the rest of the populations, had the second highest correlations to stature.

One explanation previously given as to why a formula from one population might work when applied to another has always been that the populations have similar body proportions. That appears to be the

TABLE 5

STATURE ESTIMATE COMPARISONS

(Female Means and Standard Deviations in cm)

Method	Arikara (33)	Aleutian (16)	Alaskan (48)
Sciulli	151.43 ± 5.07	139.84 ± 4.92	142.11 ± 5.56
Fully	**153.59 ± 4.46**	**144.78 ± 3.89**	**144.81 ± 4.86**
McCarthy	153.76 ± 4.14	144.91 ± 3.57	144.64 ± 4.38
F/S Ratio	155.62 ± 6.19	144.08 ± 6.47	148.37 ± 7.02
Genoves	156.65 ± 4.30	145.26 ± 3.73	148.67 ± 4.28
T & G '52	159.78 ± 4.33	149.77 ± 4.18	151.73 ± 4.62
Sjovold	158.63 ± 4.48	150.27 ± 4.69	153.37 ± 5.09

(Male Means and Standard Deviations in cm)

Method	Arikara (30)	Aleutian (21)	Alaskan (50)
Sciulli	163.35 ± 4.43	152.03 ± 3.69	152.66 ± 5.27
Fully	**165.22 ± 5.07**	**153.07 ± 3.70**	**152.12 ± 5.83**
McCarthy	165.20 ± 4.52	152.91 ± 4.20	152.10 ± 5.79
F/S Ratio	167.86 ± 6.57	156.12 ± 5.84	157.88 ± 7.33
Genoves	167.80 ± 2.95	156.19 ± 2.35	158.76 ± 3.91
Sjovold	167.50 ± 4.76	158.99 ± 4.23	160.27 ± 5.31
T & G '52	170.92 ± 4.10	160.64 ± 3.69	161.31 ± 4.97
T & G '58	171.41 ± 3.97	161.44 ± 3.31	162.09 ± 4.82
T & G Mon	171.38 ± 3.85	161.72 ± 3.20	162.36 ± 4.66

TABLE 6

PEARSON'S CORRELATIONS TO STATURE (r)

	Arikara (f)	Aleutian (f)	Alaskan (f)
McCarthy	**0.939**	**0.944**	**0.942**
Sciulli	0.898	0.882	0.913
T & G '52	0.897	0.879	0.911
F/S Ratio	0.841	0.866	0.856
Sjovold	0.841	0.866	0.856
Genoves	0.885	0.830	0.904
	Arikara (m)	Aleutian (m)	Alaskan (m)
McCarthy	**0.944**	**0.941**	**0.958**
Sciulli	0.888	0.922	0.894
T & G (all)	0.887	0.923	0.892
F/S Ratio	0.884	0.930	0.850
Sjovold	0.884	0.930	0.850
Genoves	0.825	0.809	0.866

case here as well, with the individuals from the study of Sciulli et al.(1990) having the most similar body proportions (femur/stature ratio of 27.96 and 27.86 for females and males respectively) as the individuals in my samples (with femur stature ratios between 27.14 and 27.58). While the femur/stature ratio method itself (using 26.74 as the mean ratio) did not work very well here, it is interesting to note that the formulae calculated on Trotter and Gleser's "white" males and females (with femur/stature ratios of 26.9 and 26.5 repectively) produced results more closely correlated to the individuals in my study. The success of Feldesman et al.'s 1990 method in estimating the statures of 50 "white" male servicemen may have been due to the fact that their ratio was calculated on a very large sample, or (in their own admission) the fact that their sample populations were heavily weighted toward "whites." Although they all overestimated the mean statures of my populations, the femur/stature ratio did produce better results than the generic regression equations in all cases except for the Arikara males.

The fact that I was able to achieve such a high correlation to living stature using formulae calculated from a pooled sample was surprising at first—I had assumed that my sample populations would *support* the inability of regression equations to be applied across populations. However, after breaking down the parts of the body in terms of their percent contributions to stature, the similarities between the very tall Plains people and the much shorter Alaskans and Aleutians became apparent (**Table 7**).

While there are slight differences between groups, the percent contribution of *both* lower limbs (the most highly correlated proportion) to the overall stature differs by less than two percent across groups. The smaller contribution by the tibia of the Alaskans and Aleutians was compensated for by the greater contribution of the femur, bringing the lower limbs back into similar body proportions.

TABLE 7

PERCENT CONTRIBUTION OF BODY PARTS TO SKELETAL HT

(Means and Standard Deviations in cm)

		Skel Height	BBH	Vert Column	Femur	Tibia	Ankle
Aleut	mean	134.78	12.59	43.56	38.30	30.88	6.46
F	s.d	3.89	0.39	1.95	1.68	1.37	0.20
	%		**9.34**	**32.32**	**28.42**	**22.91**	**4.79**
Alas	mean	134.81	13.00	42.09	39.31	31.21	6.39
F	s.d.	4.86	4.25	1.98	1.85	1.57	3.14
	%		**9.64**	**31.22**	**29.16**	**23.15**	**4.74**
Arik	mean	143.59	12.78	45.09	41.01	35.06	6.69
F	s.d.	4.46	0.53	1.92	1.57	1.58	0.40
	%		**8.90**	**31.40**	**28.56**	**24.42**	**4.66**
Aleut	mean	143.07	13.31	45.05	41.54	33.13	7.04
M	s.d.	3.70	0.58	1.39	1.59	1.20	0.26
	%		**9.30**	**31.49**	**29.03**	**23.16**	**4.92**
Alas	mean	142.10	13.63	43.53	41.96	33.17	6.99
M	s.d.	5.83	5.37	2.49	1.92	2.00	3.49
	%		**9.59**	**30.63**	**29.53**	**23.34**	**4.92**
Arik	mean	154.83	13.37	48.39	44.58	37.91	7.40
M	s.d.	5.07	0.43	1.92	1.77	1.50	0.47
	%		**8.64**	**31.25**	**28.79**	**24.48**	**4.78**

Noting the shortened proportions of the distal lower limbs in the Alaskan and Aleutian populations, I examined the distal limbs of the arms for evidence of the same phenomenon. In **Table 8**, the relationship of the proximal to distal limbs is illustrated.

TABLE 8

DISTAL TO PROXIMAL LIMB PROPORTIONS

(Measurements in cm)

	FEMUR	TIBIA	T/F	HUMERUS	RADIUS	R/H	ARM/LEG
Alask f	39.31	31.21	**79.37%**	28.53	20.47	**71.74%**	69.48
Alask m	41.96	33.17	**79.05%**	30.77	22.69	**73.74%**	71.16
Aleut f	38.30	30.88	**80.64%**	27.77	20.77	**74.82%**	70.18
Aleut m	41.54	33.13	**79.75%**	30.15	22.90	**75.95%**	71.05
Arika f	41.01	35.06	**85.49%**	29.55	23.29	**78.82%**	69.46
Arika m	44.58	37.91	**85.04%**	32.01	25.56	**79.85%**	69.79

From this table the results become clear: there are considerable differences between the distal and proximal limb bone ratios between the populations. The differences in the distal leg bone show that the Alaskan and Aleutian populations have tibiae that are (on average) five percent shorter for any given stature than the South Dakota Arikara. The differences in the radius to humerus ratios are even more pronounced in that the radii of the Alaskan females are more than seven percent shorter than those of the Arikara females (and the Aleutians are intermediate in both cases). The populations in the chronically cold climates of southwestern Alaska and the Aleutian Islands were shorter-statured and had relatively shorter distal limbs than the individuals from the Northern Great Plains. To what could these differences be attributed?

Prince and Steckel (1998:11), who researched other Native American groups on the Great Plains, dismissed the idea that genes were responsible for their tall statures, stating, "ethnically different populations that grew up under good environmental conditions are approximately the same height, which suggests that genetic factors account for at most a small portion of average height differences across a diverse group of populations." Tanner (1994) also pointed out that while genes are most responsible for variations between *individuals* of a population, variations between groups is best explained by similar factors such as nutrition, disease, and environmental stresses.

After researching the dietary habits of the Arikara, I found isotopic and archaeological evidence that attested to their subsistence on a combination of intensive maize agriculture and seasonal hunting, with great reliance on bison meat (Tuross and Fogel, 1994). Their agricultural harvests yielded not only enough food to sustain themselves, but also surpluses with which they could trade for goods they could not obtain or grow themselves.

Although the Arikara had made the transition from hunting and gathering to agriculture, they had managed to avoid many of the negative consequences accompanying this shift (that many other Native groups had not). They had experienced no reduction in sexual dimorphism that accompanied the increased dependence on nutritionally poor agricultural crops like maize. I calculated the degree of sexual dimorphism of the Arikara in my study using the sexual dimorphism index (SDI) equation

$$\frac{\text{Male mean - female mean}}{\text{Female mean}} \text{ X } 100.$$

The result, 7.57% (along with a mean stature difference of *11.63* centimeters in favor of the males) demonstrated that the Arikara had not suffered any substantial subsistence shift stresses. Stature itself is a poor indicator of sexual dimorphism; however, my results do support the previous conclusions of Theodore Cole (1994). He examined the cross-sectional shape of the shafts of the femur and tibia (measurements not having any bearing on stature) and found that males had a higher antero-posterior (AP)/medio-lateral (ML) ratio for both the tibial shaft and the midshaft of the femur. He concluded that there had been no reduction of sexual dimorphism with the shift to agriculture. Their tall stature, then, was due to their exceptional dietary conditions assisted by climatic conditions, good hunting resources, and accessibility to trade networks.

Was poor diet, then, to blame for the short stature and short distal limbs of the Alaskan and Aleut populations? Moran (1982) claimed that even with the shortage of plant materials, the diet was probably "at least nutritionally adequate," high in protein and fat, and low in carbohydrates. Adequate vitamins (such as A, D, B, and K) were supplied by their meat-heavy diet including seal, walrus, caribou, and fish. It is possible, however, that being high in phosphorous and low in calcium, this high-protein diet could lead to bone loss, calcium homeostasis abnormalities, and possibly even abnormalities in glucose homeostasis (Moran, 1982: 130-131). If so, this could help explain the incidence of vertebral compression fractures in my Alaskan sample. Not everyone agreed with Moran's conclusions, however. Larsen (1987: 257) observed that Eskimos showed a higher rate of bone replacement following bone resorption than the Arikara, suggesting that their meat-laden diets provided sufficient amino acids for bone deposition and synthesis.

The short stature and smaller degree of sexual dimorphism for the Alaskans and Aleutians (5.05% and 5.73% respectively) is probably not due to any substantial subsistence *change*, but may be a strong indicator of other environmental stresses. Size reduction itself may be an adaptation to limited resources. Smaller individuals may be better able to function and survive than larger ones in times of reduced food resources.

Climate undoubtedly plays an important role in the regulation of size in these populations. Extreme conditions may depress growth rates and affect adult stature. The shortening of the distal limbs in the populations adequately demonstrates Allen's law for reducing heat loss in warm-blooded species in chronically cold environments. Newman pointed out that

> changes in body form corroborate each other, and…form a distributional pattern too closely associated with gross climatic variations to be fortuitous. That this distributional pattern in body form…follows Bergmann's and Allen's rules indicates that we are dealing with adaptive changes (1953:325).

D. F. Roberts also acknowledged that indigenous populations show a "marked relationship between the morphology of the body and the climate of the region inhabited" (1978:34). The overall stature, small degree of sexual dimorphism, reduced distal limb proportions, and even certain bone pathology of the individuals in this study sample supports the conclusions made by previous researchers.

CONCLUSIONS

To conclude this study, I returned to the research questions I formulated at the beginning and determined how successfully this thesis was able to answer them. Here are the questions in review:

1. What is the best (most accurate) method for reconstructing stature?
2. Do population-specific traits matter in stature reconstruction?
3. How do body proportions contribute to stature differences between groups and what effect do they have in the inter-populational applicability of regression equations?

Although the questions were asked separately, the answers are inherently and completely connected to each other and to the fundamental process of stature estimation. First, the method to be used to reconstruct stature depends on the condition of the skeletal remains being used. This study has shown that the Fully anatomical method most accurately recreated the statures of individuals of European and African descent when compared to "living statures" on file for each individual. Because the adjustments for soft tissue utilized in the Fully anatomical method have been shown to be stable for both sexes and applicable to all ethnicities, it should also produce the best estimates of stature for all individuals with sufficiently complete skeletal remains. The only questionable aspect to this method is with regard to older individuals for whom some adjustment must be made; however, this adjustment was hardly given mention in the literature, and was not a factor for other researchers using the method (Lundy, 1985, 1988, and Sciulli et al. 1990) because their populations were relatively young.

The use of this method over the regression equations of other researchers is directly related to the other two research questions. Population-specific statistics are vital in determining whose equations will perform best when applied to other populations. Whether a population as a whole is relatively tall or short-statured, it is the *overall* similarities in body proportions that produce the best results from one population to another.

Trotter and Gleser demonstrated in their 1958 study that their formulae for the tall African Americans could also be used for the Puerto Ricans due to their similarity of proportion. This inter-populational applicability was illustrated well in my study also, as the tall Arikara from South Dakota were similar enough to the shorter-statured Alaskans and Aleutians that regression formulae created on the pooled sample produced extremely high correlations to both the sample populations as well as 12 individuals randomly selected from outside the original study sample.

Ruff and Walker (1993) advocated the examination of the brachial and crural indices as a way to find correct body proportions and to determine which modern reference samples (having approximately the same proportions) would produce the best estimate of stature and body weight for an unknown individual(s). This method worked well for their fossil hominid; however, based on my research, it is possible to conclude that the reference population does not necessarily have to have exactly the same body *shape* to estimate an individual's stature.

Based on the results of this research, I also cannot recommend the use of Trotter and Gleser's equations as a "fallback" just because they have been utilized by so many for so long. Their equations most overestimated the mean statures of all my study groups as they had for many other researchers (Genoves, 1967; Sciulli et al., 1990; Feldesman et al., 1990; Ruff and Waler, 1993). A review of the literature (such as the one provided here) is sufficient to illustrate that these equations, like those of most other researchers, apply best to the populations from which they are formulated, and should be used only when the individual or group being estimated has similar body proportions.

The use of generic stature estimation methods produced poorer results than I had expected. Both overestimated the mean statures of my study populations (although to a lesser extent than the Trotter and Gleser equations) with no increase in correlation to living stature.

This thesis has also demonstrated how much stature estimation can contribute to areas of anthropology outside of physical anthropology alone. Stature has been used to infer social structure and status among prehistoric populations, and has been utilized, in part, to examine the detriments to health (both nutritionally and behaviorally) brought about by major subsistence changes in the past, such as the agricultural revolution. Studying stature in populations in extreme environmental situations can help illustrate how adaptable humans (and other warm-blooded species) can be to the environment. Changes to stature--sometimes marked changes over very short periods of time--when environmental conditions are altered can dramatically illustrate the extent to which the environment determines how our genetic inheritance will be manifested.

Stature is a measure not only of how tall people are. It is the end result of the interactions between the environment in which they live and the behaviors in which they engage. Because these conditions apply to every human population, stature can be a vital part of the study of any population, living or prehistoric. For this reason, and until a method is found that can *truly* be applied without regard to sex or ethnicity it is very important for researchers to continue to conduct studies of stature and publish their findings for others in the field to utilize.

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