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THE IMPORTANCE OF INDIVIDUAL AND POPULATION VARIATION TO HUMAN STATURE ESTIMATION

By

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The Importance of Individual and Population Variation to Human Stature Estimation

Dr. Ashley McKeown

Human stature estimation is a central part of forensic anthropological investigation. It is one of several factors used to identify unknown individuals. The statistical relationship between body length and body segment length allows for long bone lengths from an unidentified individual to be used in a linear regression equation to estimate living stature. These linear regression equations are often formulated from a data set of an entirely different population. This research explores the necessity for the unknown individual to be similar on a number of points to the known population that makes up the equation. Populations are highly variable, and one or two equations should not be applicable for every population. The sample to be examined consists of 22 Hispanic males with known stature and long bone lengths, drawn from the Forensic Data Bank. This data was applied to some of the most commonly used equations today, including: Trotter and Gleser's Korean War equations, Hispanic and American White equations from FORDISC, and Genoves' Mesoamerican equations. Statistical analysis revealed the necessity for more data collection from Central and South American populations. If this were done, a greater number of unknown individuals could be identified and their remains returned to their families.

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Thank you one and all. You have made my journey both possible and pleasurable. This is a time I shall never forget and I will always carry a part of you with me as my career advances.

Lovingly,

Kelly Shields

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Chapter I.

The estimation of stature in forensic anthropology is one of several important factors contributing to the identification of missing persons. Due to the biometrical relationship between body segment length and total body length, estimation of a person's living stature can be conducted by measuring the length of only one long bone (Keen, 1953). The most accurate long bones to use for this analysis are the femur and tibia (Genoves, 1967; Trotter, 1970).

When human remains are discovered, forensic anthropologists can measure long bones, and apply their measurements to linear regression equations. These equations are developed to estimate stature from known living stature or cadaver stature, and long bone data collected from a similar population. The estimated stature is then compared with both recorded and reported stature of missing individuals. If several of the identification factors, such as sex, ethnicity and age, as well as stature, correlate with one individual, then they are typically considered identified.

The primary issue with this method of stature estimation is that body segment proportions vary between populations. The long bone lengths of one population do not necessarily correlate with the same stature in another population (Genoves, 1967; Keen, 1953). This is most likely due in small part to the genetics of the population, and in large part to the environment in which they live.

It is my contention that the reference population, of which the stature estimation equations are developed, must be similar on a number of variables to the questioned population. This includes accounting for variation due to environmental factors like nutrition and climate, as well as migration, genetics, secular change in growth, and allometry. If the data required for stature estimation were collected from more populations, then more accurate equations could be developed, and stature estimation would improve, resulting in a greater number of identified people.

Population variation due to environment is the primary reason why one stature estimation equation cannot be applied to a variety of populations. The environment affects growth. People, particularly of lower socioeconomic status, that live at high altitudes, or have experienced poor nutrition and health, tend to not reach their true genetic potential (Larsen, 1997; Pawson et al., 2001; Stinson, 2000). However, if these people place themselves in a healthier environment, they can reach their genetic height, as can their children. Sometimes this is through migration, or simply by improving their lifestyle (Eveleth and Tanner, 1990; Kaplan, 1988; Stinson, 2000). While environmental affects appear to be the primary controlling factors in an individual achieving their stature potential, genetics can play a role, particularly in late adolescence and under conditions of poor nutrition (Kondo and Eto, 1975; Wolanski, 1970).

Two more significant considerations when comparing populations are the secular change of a population and the degree of allometry. Secular change is the increase or decrease of size over time in a population, and allometry is the proportional relationship of anatomical structures in humans and other biological organisms (Bogin, 1999; Roche, 1979). Both of these factors are important concerns when comparing populations. Populations vary in their degree and locality of allometry, and secular change can occur in a population in a relatively short period of time. This is particularly significant if the populations you are comparing are from different geographic areas or time periods.

Various parts of the body may respond differentially to changes in the environment or develop at different rates (Jantz, 1997). Both environment and genetics play a role at different stages of a child’s development, and vary between even two closely related populations (Ruff, 2002). Other factors such as age and population differences in height between the sexes must also be considered, as well as the inherent human flaw in using self-report data for known living stature. People tend to over estimate their own height, and different agencies measure height use a variety of methods.

Population variation due to genetics and environment are the primary concerns of this paper, however several authors referenced with in the paper have grouped their subjects according to racial designations, which have to be assumed here to represent geographic and biological populations. Long-term (over 100,000 years) residents of a geographic area share observable physical characteristics that may identify them as members of that area, often termed “races” (Brace, 2000). What occurs over time is a physical adaptation to the environment (Brace, 2000). So, what is often seen as different “races” is really common ancestry from a shared geographic area. It is important to understand that race is not biological, and that the differences observed between humans are really small genetic differences, and environmental adaptations.

In Central and South America frequent political unrest, natural disasters and human rights atrocities claim the lives of many of the poor and leave vast numbers of unidentified bodies. These populations are not currently represented in stature estimation equations, and without better methods of identification they will remain unidentified. The development of equations for more populations is necessary to account for biological variation, to identify these people, and return them to their families. This study examines the efficacy of stature estimation for Central and South American populations by assessing the accuracy of formulae currently available.

A data set of Hispanic males was chosen in order to closely examine the relationship between the reference sample and the questioned population in stature estimation equations, as well as shed light on the importance of accurate estimation equations for Central and South American populations. This data set of living stature measurements and long bone lengths was chosen to apply to commonly used stature estimation equations and a set of Mesoamerican stature equations. The data set was provided by Dr. Richard Jantz of the University of Tennessee, and taken from the Forensic Data Bank. This data set includes living stature and femur and tibia lengths for 24 Hispanic individuals. The Forensic Data Bank is the product of forensic anthropologists across the country continuously recording and reporting data on recent populations.

Long bone measurements from the data set were applied to Trotter and Gleser's American White, Mongoloid and Mexican equations, as well as the American White and Hispanic equations in FORDISC and Genoves' Mesoamerican equations (Genoves, 1967; Jantz and Ousley, 1993 - 2005; Trotter and Gleser, 1958). These equations were chosen because they are the most likely equations to be applied by forensic anthropologists estimating stature, in a Hispanic population today. Each set of equations included one equation with the tibia, one with the femur, and one with both, if available. Only these bones were applied because they are the most commonly used and the most accurate bones for estimating stature (Genoves, 1967; Trotter, 1970).

The Trotter and Gleser, and FORDISC equations are some of the most commonly used today for all populations. Trotter and Gleser (1952, 1958, 1970) developed their stature estimation equations from the Terry collection of medical school cadavers in the United States, as well as American World War II and Korean War casualties. FORDISC (Jantz and Ousley, 1993 - 2005) is a computer program developed to allow for quick and simple analysis of skeletal measurements through the application of Howell's data set and modern forensic data. Genoves' (1967) equations are also commonly used for estimating stature in Hispanic populations and were created by compiling cadaver and long bone measurements in Mexico.

The Hispanic data from the Forensic Data Bank was applied to each of the various formulae in order to generate stature estimates. For each equation, mean, high and low values were calculated for every measurement to develop a range in which the living stature should fall. Error and bias were calculated to determine which equation was most accurate for the sample, and significance of the relationship between estimated and known stature were tested using paired t-test and Pearson's correlation analyses.

Stature estimation should involve a complex analysis because populations differ on a number of issues, and its application should be made with caution. Estimations using a reference sample that is not similar on many accounts to the questioned sample will likely result in a poor estimation of stature. Taking into account the many variables that exist in a population, and finding another population on which we have adequate data and equations, may be difficult, but necessary for gathering accurate stature estimations.

Ross and Konigsberg (2002) used Trotter and Gleser's American White equations to estimate stature for Eastern Europeans and came to a similar conclusion, that new equations must be created for populations not well represented by the equations commonly in use today. To improve stature estimation for populations such as Central and South Americans it is imperative that more stature data be collected, and a greater number of estimation equations developed to account for the variety found in modern human populations.

Chapter II. BACKGROUND

History of Stature Estimation

A number of methods have developed in the last few centuries for stature estimation. One particularly time consuming method involves taking the sum of the heights of all skeletal elements. This method is rarely used, however, due to the number of hours required, and it is relatively rare to recover a complete human skeleton in forensic cases. Other methods developed require only the measurement of one or two long bones, rather than the sum of all skeletal elements. The proper measuring technique for skeletal elements and the derivation of correct equations for estimating stature from the measurement of a few long bones has been the subject of many research papers.

In the first study of its kind, Rollet assessed the correlation between stature and long bone length (Rollet, 1888 in Trotter and Gleser, 1952). He measured the lengths of the radius, ulna, humerus, fibula, tibia and femur of adult French cadavers and published a report with the methods of measurement, the individual measurements, and tables of stature estimations. His tables showed the correspondence of stature to long bone lengths for each side of the body. He measured fresh cadavers and later remeasured their dried bones, and concluded that when analyzing dry bone, a two millimeter loss must be calculated to account for shrink during the drying process. This allowed him to apply dry bone to his stature estimation tables (Rollet, 1888 in Trotter and Gleser, 1952).

Pearson (1899) used Rollet's data to create regression formulae for estimating stature. He used only long bone lengths of the right side, unless they were missing, in which case he used the left. Pearson (1899) found through analysis of Rollet’s data that age shrinkage was not a significant factor for stature estimation. Mildred Trotter and Goldine Gleser, however, later provided evidence that age shrinkage is a significant consideration when estimating stature (Trotter, 1970).

Pearson (1899) contributed greatly to the advancement of stature estimation, and discussed the applicability of using a stature estimation equation on more than one population. He stated, "the individual variation being greater than the ethnic, is not a valid argument for applying a formula based on the observation of one local race straight away to a second" (Pearson, 1899 p.176). Just because there exists greater variation within races than between them, does not mean stature estimation equations can be widely applied to different races (American Anthropological Association, 1999; Pearson, 1899). If stature regression formulae are to be applied to more than one race, it must be done with careful consideration. Pearson stated that "the real test of the applicability of the formulae is whether or not they give for another local race of which we know à priori the stature, results in agreement with themselves and with the known stature." (Pearson, 1899 p.178). Pearson also recognized that his formulae should not be construed as the final word on measuring stature, and that they are only representative of his data (Trotter and Gleser, 1952).

According to Dupertuis and Hadden (1951), Pearson's formulae were derived from measurements of populations that were particularly short in stature. They decided it was necessary to create new formulae representative of taller populations. They were, like Pearson, unsure if formulae derived from one race would be applicable to other races. Dupertuis and Hadden (1951) calculated their new formula using cadavers of tall Euro Americans and African Americans from what is now the Todd osteological collection, currently housed at the Cleveland Museum of Natural History. By suspending the cadavers, Dupertuis and Hadden (1951) were able to measure their stature from the standing position, hopefully reproducing living stature. They found that using two or more long bone lengths is more reliable that just one, and that using bones from the lower extremity is more accurate than using bones from the upper limb. They also discovered, just as Pearson did, that estimation formulae apply best to the population from which it was derived (Dupertuis and Hadden, 1951).

If the recovered remains are relatively complete, then a method such as the Fully technique, developed in 1956, might be applicable (Raxter et al., 2005). This is a time consuming method where height measurements of skeletal elements are added up from heal to head. This method is rarely used because it is not time efficient and requires a nearly complete skeleton.

Mildred Trotter and Goldine Gleser developed equations that are still used for stature estimation today. They took advantage of the repatriated deceased from World War II and the Korean War by measuring long bone lengths from male cadavers and comparing them to military records containing living stature (Trotter, 1970; Trotter and Gleser, 1958).

The military has a prescribed manner for measuring individuals who enter their ranks. So, although those cadavers analyzed by Trotter and Gleser were measured initially by many different examiners, it has to be presumed that they followed the strict protocol prescribed by the military, minimizing inter-observer bias (Trotter, 1970). Long bone lengths from each side were paired and averaged to derive equations from the World War II data. The Korean data was analyzed later, at which time Trotter and Gleser decided it was more appropriate to formulate equations from the left and right side separately, combining them later for each of the racial groups (Trotter, 1970). If one side was incomplete or missing, then the length of the other side was used in the equation. They found the advantage of using the average of the pair of bones was minimal. The regression equations they formulated were based on the linear relationship produced between the variables of stature and long bone lengths (Trotter, 1970).

Trotter and Gleser (1970) also used cadaver measurement data from civilian cadavers assigned to Washington University School of Medicine in St. Louis, Missouri. The skeletons of these individuals later became part of the Terry collection. The Terry collection data permitted an analysis of the effect age has on stature, as well as the development of equations for females (Jantz, 1992; Trotter, 1970). The combined civilian and World War II data enabled "a survey of possible trends in maximum adult stature of White and Negro males born over a range of 85 years" (Trotter, 1970 p.75). Trotter and Gleser found that stature declines with age, and that this trend is independent of long bone lengths. They speculated that thirty years was approximately the age where stature begins to decrease at a rate of 0.06 cm per year (Trotter, 1970; Trotter and Gleser, 1952). As a result, they created a formula that corrected for age in stature estimates.

Trotter and Gleser (1952) also compared the average stature of the cadavers from Washington University School of Medicine to that of a sample of the living population and found that the average cadaver was approximately 2.5 centimeters taller than the average sampled living stature. They concluded that it was reasonable to expect greater stature when measuring cadaver length, and incorporated this 2.5 centimeter adjustment into their calculations of living stature from cadaver length.

Trotter and Gleser (1952, 1958) developed linear equations from long bone lengths of young adult Americans for estimation of stature. These equations are most accurate when applied to the data from which they were derived. This data includes American White and American Black males post-World War II and from the Terry collection, as well as Mongoloid, Mexican, Puerto Rican, American White and American Black males from the Korean War data (Trotter, 1970). The Mongoloid and Mexican data are subject to greater sampling error because they are from relatively small and heterogeneous groups. The Mongoloid groups consist of Japanese, Hawaiians, Filipinos, and Native Americans (Trotter, 1970 p.82). For better stature estimation of these populations, a random sample must be conducted on these poorly sampled groups from the Trotter and Gleser study.

According to Trotter and Gleser, the evidence indicates that in order to develop accurate estimates of stature, equations used on the unknown individual must be derived from a "representative sample of the population of the same sex, race, age, geographical area, and time period to which the unknown is believed to belong" (Trotter, 1970 p.82). The equations developed by Trotter and Gleser are primarily of American Whites and Blacks, and should only be used to compare with these populations. However, these equations are currently being applied worldwide because of the scarcity of stature data.

Richard Jantz, David Hunt and Lee Meadows (1994) found evidence that Trotter and Gleser's 1952 stature estimation formulae using tibia lengths are inconsistent with Trotter's definition for measuring the tibia. According to the Jantz et al. (1994), the definition for measuring tibia length that Trotter provided, includes the malleolus. Trotter herself encountered inconsistencies between the World War II data she measured, and the Korean War data that was gathered by technicians who used her definition (Jantz et al., 1995). She found the World War II data to have significantly shorter tibia lengths than the Korean War data, although she didn't appear to investigate this further. Jantz and colleagues (1994) originally suspected this difference was due to allometric secular change, change in body proportions over time. Now they believe that Trotter did not measure as she herself prescribed, and in fact excluded the malleolus from her tibia measurements. Jantz and his coworkers (1995) warn against using this tibia data due to the inconsistencies in measurement. However, they allow that if Trotter and Gleser’s tibia data must be used when analyzing their data, then the malleolus should be excluded for analysis of the World War II data (Jantz et al., 1995). Analysis using the Korean War data should be accurate because Trotter herself did not conduct the measurements but sent directions for their measurement, which included the malleolus.

Jantz (1992) provided modifications to the Trotter and Gleser formulae for estimating female stature to allow for the change in body size over time, also known as secular change. Trotter and Gleser developed their formulae for female stature from the Terry collection that contains skeletons from individuals who died in the early 1900's. According to Jantz, these formulae are not appropriate for use in modern forensics because there has been a significant change in body size since that time (Jantz, 1992).

Jantz used the Forensic Data Bank at the University of Tennessee to calculate new regression intercepts for American females, altering Trotter and Gleser's formulae. He developed this by analyzing "femur and tibia lengths from modern forensic cases and modern height data from anthropometric surveys" (Jantz, 1992 p.1230). Jantz states that the performance of the formula for identifying modern individuals is improved by the new regression intercepts.

FORDISC (Jantz and Ousley, 1993 - 2005) is a computer program that allows for classification of unknown adults with regards to sex and ancestry, based on known samples (Ubelaker, 1998). Later editions of this program also provide stature estimation formulae. This interactive computer system was created primarily using data from the Forensic Data Bank at the University of Tennessee. The Forensic Data Bank is the result of the hard work by scientists across the country, recording and reporting modern forensic cases using standards provided by Moore-Jansen and colleagues (1994) in their FORDISC manual.

FORDISC 1.0 (Jantz and Ousley, 1993) was the advent of a new system where custom discriminant functions for estimating sex or ancestry could be created using modern data for just a few available cranial measurements (Ubelaker, 1998).

FORDISC 2.0 improved upon the previous version by including the Howells data set, which provides data from populations worldwide (Howells, 1973). Postcranial measurements from the Forensic Data Bank were also included for stature estimation (Ubelaker, 1998). Measurements of a variety of bone lengths can be used, and one or multiple bones can be applied to derive a linear regression equation or stature estimate. FORDISC 3.0 (Jantz and Ousley, 2005) became available in 2005. This version is an update of the previous version, with a few improvements including: a larger number of variables and groups, as well as an improved guide to measurements and better file management and printing capabilities.

This program offers stature formulae for use with multiple different combinations of long bone measurements, which is particularly advantageous in the case of a partial skeleton (Ubelaker, 1998). It also arranges them in order of increasing estimation error, and includes Trotter and Gleser's (1952) World War II formulae (Ubelaker, 1998). The equations provided by FORDISC, based on the Forensic Data Bank and the Trotter and Gleser formulae, are the most commonly used in forensic anthropology today, though they are not applicable to all populations.

Equations were developed by A. Ozaslan and coworkers (2002) to estimate stature from body parts. Steele and McKern (1969), and Wright and Vasques (2003) also created methods for estimating stature from fragmentary long bones. This is particularly helpful in mass disasters, where sometimes only a single identifiable element is discovered. Ozaslan et al. (2002) focused on estimating stature from the lower extremities of dismembered bodies because these have a higher correlation with a person’s height than do the upper extremities. Steele and McKern (1969) and Wright and Vasques (2002) developed equations using fragmentary long bones. Wright and Vasques (2003) compared the equations that they developed from studying fragmentary Mayan long bones to those Steele and McKern had created over thirty years earlier from Mississippian archaeological remains. They discovered as Ozaslan et al. (2002) had, that these equations are population specific and population variation must be taken into account when estimating stature.

Environment and Genetics

Accurate stature estimation from long bone measurement is particularly important in Latin America where natural disasters and recent political upheaval have resulted in large numbers of unidentified and partial sets of human remains. Establishing good data for such a region requires understanding the major factors that impact stature in a population. Since European contact the genetic pool for these populations has become more mixed, however, there is scant evidence for this having more than a very casual impact on Native American stature. The environment in which a population lives primarily affects human stature. This includes nutrition, altitude, and health care.

Before birth and during growth years we are susceptible to malnutrition, illness, climate, and other factors which affect stature. Once adult height is reached, food no longer has an effect on stature (Stewart, 1943). Each stage of growth however, is associated with a different type of influence.

During the prenatal period, and infancy, the rate of growth is rapid, and then it slows down, and increases again at puberty (Stinson, 2000). Before birth the environment has a small effect on growth, however, during infancy and childhood, individuals are highly susceptible to environmental insult. Growth disruptions during this time are the primary cause of small body size in adults. In late adolescence genetic factors begin to play the leading role in influencing stature (Kondo and Eto, 1975).

The growth pattern for populations living with chronically low dietary intake is different from healthy populations. Undernourished populations generally have reduced adult height by 10% (Frisancho, 1993). This is primarily due to the uniformly slow rate of growth in these populations, which is correlated with a late growth spurt, as well as slow growth before and during adolescence.

Nutrition

Studies of living populations have shown that growth stunting in childhood is strongly correlated with short stature in adults. If nutritional stress is not overly severe, it may simply slow physical development and increase the individual's susceptibility to infectious disease; however, if it is severe, it can result in death (Newman, 1962). Important ecological factors that may influence nutrition include: the disease environment, the climates influence on dietary needs, and the food producing ability of the soil and climate. Biological factors involved are acclimatization and adaptation to stressful conditions. Terminal height is generally a product of nutrition and disease load throughout the growing years. Those individuals with adequate nutrition in childhood tend to reach their true genetic growth potential, whereas those with a poor nutritional history do not (Larson, 1997).

Genetic factors exert the most influence during adolescence. However, under conditions of malnourishment, the impact of genetic control may be diminished, and it is during childhood that skeletal maturation of the individual is most influenced by chronic malnutrition (Kondo and Eto, 1975). Frisancho (1980) discovered the impact of nutrition on children while studying adolescents of similar socioeconomic status, but diverse genetic backgrounds in Peru. His study of the Quechua, a native population, and the Mestizo's, a mixed native and European people, showed that genetics did not affect stature in the children of these groups as much as did their environment. Pawson and colleagues (2001) also studied indigenous populations in the Peruvian Andes; however their populations were genetically homogenous with varied socioeconomic statuses. Pawson studied the genetically similar residents of two cities, one of which had recently undergone an economic boom. He witnessed the impact of improved health care and nutrition on the more advantaged population and came to a similar conclusion as Frisancho (1980). These studies found that factors like nutrition and health care are the primary regulators for variation in height and weight in children.

Socioeconomic status dictates the environment people live in, which can in turn affect their health and play a significant role in overall stature. Children living in households with high socioeconomic status tend to be taller on average than children living in low socioeconomic homes (Eveleth and Tanner, 1990; Stinson, 2000). These differences are due to several factors including: "nutritional status, disease rate and medical care between socioeconomic groups" (Stinson, 2000, p 430). Leonard and colleagues (1990) discovered, much like Pawson et al (2001), that nutritional factors significantly contribute to the slow and reduced growth of poor children. They also examined a small homogeneous population in the Peruvian Andes, and found that children from higher socioeconomic families are significantly taller and heavier than those of lower socioeconomic status. Poor socioeconomic conditions allow environmental influences to severely impact stature in the more impoverished segments of society.

Poor countries, as well, have greater variation in stature due to environmental factors, than do wealthier countries (Silventoinen, 2003). In the United States only approximately 20 percent of variation in stature is due to the environment, while in developing countries the environment has a significantly greater influence due to the reduced amount of protein in the diet, poor nutrition, and disease, all playing heavily into the delay of growth.

Catch-Up Growth

The majority of environmental factors that affect growth are related to nutrition and childhood infection. Growth will slow during an illness, and in wealthier countries, there is potential for catch-up growth. However, in impoverished countries catch-up growth is unlikely (Eveleth and Tanner, 1990).

When children have experienced growth stunting, it is possible for them to improve their stature through catch-up growth. Catch-up growth occurs when a period of growth disruption is followed by a period of enhanced growth, or when the growth period is extended (Stinson, 2000). Catch-up growth is rare because the majority of children stay in the environment in which they were raised and that created the initial stunting. If circumstances change and improve, then these children have the potential for catch-up growth. The energy needed to catch-up in growth is significant, and considerably larger than the normal velocity. In countries with poor nutrition, the residents are typically unable to achieve this level of energy, and cannot obtain catch-up growth, so remain stunted (Eveleth and Tanner, 1990).

Small body size is likely an adaptation to poor socio-economic conditions, or situations of dietary stress (Frisancho, Sanchez, Pallardel, and Yanez, 1973). Larger bodies demand greater energy resources and nutritional requirements for their maintenance and growth. Research suggests that the observed high offspring survival rate for parents with small bodies reflects a developmental adaptation to poor socio-economic conditions. Stinson (2000) however, claims that there are no circumstances in which stunting can be considered an advantage because it reduces immune function, and leads to a lowered activity level.

Hypoxia

High altitude hypoxia occurs when "the oxygen in the air at high altitudes is less concentrated and, consequently, is at a lower pressure than it is at low altitudes" (Frisancho, 1975, p 313). For example, at 4,500 meters the partial pressure of oxygen is decreased up to 40 percent (Frisancho, 1975). The effects of hypoxia include increased heart rate, shortness of breath, physical fatigue, digestive disorders, and many more. The effects of high altitude hypoxia become evident at around 4,920 feet, and at 33,000 feet human physiological tolerance is reached (Frisancho, 1975, p 313-314).

Growth retardation is proportional to the degree of hypoxia, and hypoxia exists along an altitude gradient (Pawson, 2001). An altitude gradient refers to "the partial pressure of oxygen in the air which decreases proportionately with an increase in altitude" (Frisancho, 1975, p 313). Pawson (2001) conducted a study of two Andean populations, of which one was more mobile, likely due to socioeconomic factors. He attributed the greater height of this mobile population to their frequent movement to lower altitudes. According to Pawson, analysis shows that there is a consistently negative association between time spent at high altitude and measurement of height. Pawson could be correct in his analysis, and high altitude could be the underlying cause of the difference in stature between his two populations, or as other authors have discovered, environmental factors such as nutrition, and socioeconomic factors like health care, could be playing a significant role in the stature discrepancies between his two populations.

Migration

Migration is the movement of individuals or groups of people from one geographic location to another (Lasker and Mascie-Taylor, 1988). According to Bogin (1999), "migration redistributes the genetic, physiological, morphological, and sociocultural differences found in human populations" (p.297). This would suggest that by changing the environment and genetics of a population, migration can ultimately affect the growth and development of migrants, as well as the recipient population.

When considering migrants its important to take into account who is migrating and why. Migrants generally are not representative of the populations they come from. Groups vary depending on why they migrate. Whether they move due to employment, politics, or natural disaster, it is rare to have a representative sample of a population move at once (Roberts, 1988). Migration changes the demographics of the giving and receiving populations, as well as transferring genes from one locality to another, increasing the genetic variability for both populations, unless the migration is one way.

Humans are plastic and will adapt to selection or changes in environment during childhood. Franz Boas (1912), studied immigrants and their American born descendants for the United States Immigration Commission. He found that American born descendants of immigrants develop differently from their foreign-born parents. According to him, this is most likely due to the influence of the American environment.

Sparks and Jantz (2003) reanalyzed Boas' study and came to the conclusion that he may have overstated his findings, which they also believe are outdated. Sparks and Jantz compared Hebrew parents and their European born adult offspring, United States residents for under five years, and found results much different from Boas. They discovered that the offspring had narrower and shorter heads, with respect to sex, than their parents. Boas observed change in the opposite direction. Sparks and

Jantz suggest that this change is not due to environmental influence, but is genetic. While neither analyzed stature, human plasiticity in general can be derived from their analyses. The conflict in their results may be due to the very different samples they analyzed. Sparks and Jantz examined adults who had immigrated, whereas Boas studied American born children of immigrants. Boas analysed children, who’s stature is most effected by environment, thus his conclusions were that environment was the major factor influencing their plasticity. Sparks and Jantz’s analysed adults, and post adolescence changes in stature are most likely due to genetics, which is also the conclusion they reached.

The environment affects physiological adaptation in individuals early in life (Kaplan, 1988). If migration occurs, this adaptation may no longer be suitable for the new environment. However, offspring of the migrant will adapt to the new locale both culturally and physiologically.

Physical growth and development is a good indicator of the quality of the environment in which the individual lives (Bogin and Loucky, 1997). Through migration to the United States the indigenous Maya of Guatemala are breaking the cycle of poverty, under-nutrition and disease that exists for most of them in Guatemala (Bogin and Loucky, 1997, Bogin, 1995). The political economy in Guatemala deprives most Maya of sufficient nutrients, health care and education required for human development. Upon migration to the United States, Maya families, while still existing on a low income, have the support of the US political economy. This includes nutritional, health and educational benefits that are otherwise unavailable to most Maya in Guatemala. Children born in the United States to Maya immigrants have a tendency toward greater stature than do children born in Guatemala or Mexico, which could indicate that a greater investment in economic and social resources in their children resulted in taller stature.

This environmental effect is creating a positive trend in growth for Mayan refugees in the United States. If given the opportunity, through health care and other economic factors, they will achieve an average stature similar to other North American populations (Bogin, 1995).

Secular Change

The Maya in America, while showing a general increase in stature, are similar in body composition to other ethnic groups in the United States, though shorter overall. Bogin (1995) claims this is because Mayan children are still in the first stage of a generation-to-generation increase in stature, known as secular change in growth. Secular change is a "process that results in a change in the mean size or shape of a population from one generation to the next" (Bogin, 1999, p 243-4). Several likely influential factors have been suggested to explain secular change, most of which are associated with an improved standard of living. This plastic response in growth is due to improvement in environmental quality, which affects overall health (Bogin, 1999). The Maya in the United States are an excellent example of the plasticity of growth that Boas discussed.

A trend has erupted in the last 100 years in many countries around the world were children are growing progressively larger at all ages (Kondo and Eto, 1975). This increase in stature in recent years is particularly evident in industrialized countries. Children are growing taller, and maturing more rapidly. This trend has also been witnessed in comparative studies of immigrants and their children, like the examples of European and Guatemalan emigrants provided by Boas and Bogin.

While the cause is still largely unknown, there are many theories for this increase in stature (Kondo and Eto, 1975). Some of these include improved nutrition, increased socioeconomic status, and greater gene flow among ethnic groups. Eveleth and Tanner (1990) suggest that these factors and improved health care, sanitation, and reduced family size, are also influential in the observed positive secular increase in stature.

Following World War II the Japanese exhibited the greatest secular change thus far recorded for a single nation. Several studies have been conducted measuring secular change in height for native-born Japanese in contrast with American born Japanese. Due to their similar genetic background, the environment should be the only major factor contributing to this change in stature (Kondo and Eto, 1975). The average gain in stature per decade in native Japanese children, between 1900 and 1930, was about one centimeter for boys and 1.2 centimeters for girls. Between 1950 and 1970 the average gain was about 4.3 centimeters for boys and 3.6 centimeters for girls. Kondo and Eto believe that the rapid increase in stature largely occurred after World War II.

Evidence suggests that growth in the prepubertal period is largely dependant on the environment, where as genetics has a greater influence in late adolescence. Kondo and Eto (1975) compared their data from studying Japanese secular change, with data they had collected from Japanese-American children. They found that Japanese-American children were superior in stature increase during the prepubertal period. They attributed this difference to nutrition and other favorable environmental conditions found in the United States. Kondo and Eto (1975) also discovered that in the later stages of growth, the two populations appeared to be more influenced by genetics than environment.

American-born Japanese children are taller and more advanced in skeletal development than those of equal age in Japan, likely due to environmental factors. William Greulich (1976) came to these conclusions after his first study in 1956, of native Japanese and Japanese-Americans. Due to improved economic conditions in

Japan after his initial study, Greulich decided to conduct another analysis in 1974 to compare the adult measurements of the original group of American–born Japanese with native Japanese of the same sex and age. He found that “the difference between the average stature of the native Japanese males at 17-18 years of age and their subsequent adult stature is about four times greater than the corresponding increase in the stature of the American-born males” (Greulich, 1976, p 556). The female data show a similar trend, though on a smaller scale. Females, however, did grow more than males. In Japan, from 1900 to 1970, the average stature for males increased 7.9 cm, and girls increased 8.6 cm. Females are smaller in general than males, however, they gained 5.8% in stature, where as males gained 4.9% (Greulich, 1976). This data suggests that females are biologically more efficient than males, and that the environmental conditions that had changed in Japan, made a huge impact on stature in that population, in comparison with American-born Japanese.

Rather than a grand secular change post war, the Japanese may have merely been experiencing catch-up growth due to the devastation of war. Matsumoto (1982) conducted a study on the effect of World War II on growth in Japanese birth cohorts. She discovered that individuals who had experienced inhibited growth before puberty, during the war, later tended to experience catch-up growth. She discounted the widely held belief that positive secular trends are due to nutrition, and instead attributed any secular change found to be due to urbanization, which created a change in living standards. However, this change may have also initiated a change in lifestyle and diet.

Negative secular trends also exist. A clear example comes from Guatemala between 1974 and 1983. Civil war and wide spread political oppression dominated this period. The political unrest, serious economic decline, and resultant poor nutrition and health of the entire population, are seen as contributing factors to the significant decline observed in adolescent Guatemalan boys and girls (Bogin 1999). This example is further evidence that physical growth in human populations is sensitive to environmental stimuli, such as social, economic and political factors.

Affluent countries have recently encountered a slowing or complete stop in this trend of increased body size. Some researchers suggest this is due to a lack of further improvement in environmental factors affecting growth (Bogin, 1999). Another explanation is that we have reached our peak height, or genetic potential, and no further development is possible (Roche, 1979; Stinson, 2000). Either way, secular trends are significant factors that must be taken into consideration when estimating stature. This is particularly true when using an equation derived from a population from an earlier time period than the one on which it will be applied.

Genetics

It is generally accepted that height responds to genetic as well as environmental influences. As discussed earlier, genetics is more influential during late adolescence, where as the environment has a greater affect on height during childhood (Kondo and Eto, 1975). Genetic analysis is particularly complicated due to change in height with age, environmental variability, and height differences between the sexes. Assortive mating could also make predicting genetic influence difficult because in some cultures people select their mates according to their height, and when conducting genetic models it is generally assumed that height is randomly selected. Environmental effects, like nutrition, however, appear to be the primary controlling factors in achieving full genetic stature.

Allometry

The study of the proportional relationships between size and shape for biological organisms is allometry (Roche, 1979). The physical differences in modern humans are most likely the result of the interplay of long-term genetic factors and environmental factors during the developmental period (Ruff, 2002). Leg length and other physical characteristics in early adolescence are controlled by environmental factors, like improvements in nutrition, economic status, and health care, while those in late adolescence are controlled by genetics (Kondo and Eto, 1975). When assessing anthropometric variation, one must consider the influence of both factors in order to distinguish between them (Ruff, 2002).

Some limb bones are more susceptible to change with stature than others. This must be considered when measuring long bones for stature estimation for an individual. Meadows and Jantz (1995) examined secular change in long bone proportions, the relationship that exists between them and secular change in stature. They inspected long limb bones of Euro American and African American males from the mid 1800's to mid 1900's, examining allometric changes, and discussed what these might mean for stature estimation. Meadows and Jantz used data from Trotter, and adjusted the tibia lengths to include the malleolus, as Trotter had intended. They used allometric scaling coefficients to show that changes in long bone lengths are related to changes in height. Meadows and Jantz also used modern forensic cases, Terry and WWII data to test how secular change and proportion of lower limb bones relate. Their results show that the femur is positively allometric, meaning that these bones increase in length proportionally to stature. This suggests that the "femur-stature ratio varies with height" (p 765). If the same equation is used for all heights, then stature will be overestimated for taller individuals with longer femora. Lower limb bones in general were found to be positively allometric with stature, suggesting regression formula from shorter samples, cannot be applied to these taller individuals. The upper limb bones, however, are "generally isometric with stature" (p766), meaning the bones do not change in proportion to stature with increase in stature.

Using measurements from upper limbs is potentially problematic, as they will yield less accurate stature estimations than lower limb bones.

In an analysis of allometric secular change, Meadows Jantz and Jantz (1999) took the same sample they evaluated in 1995 and used regression formula containing bone length and year of birth. They discovered that males showed stronger secular change than females, and that the lower limb bones, in particular the distal bones, show more pronounced secular change. Meadows Jantz and Jantz suspect that environmental causes like nutrition, and disease are behind this secular change in size and long bone proportions. Holliday and Ruff (2001) are generally in agreement with Meadows Jantz and Jantz. They analyzed the proximal and distal limb segments lengths of 20 geographically diverse modern human skeletons and found that distal limb segments showed greater variation due to environmental and genetic factors, and that males and females differ in the variation they exhibit in their limb segments.

These studies have shown that differential limb proportions exist both between sexes and among populations, and that the lower limb bones will show more accurate results when estimating stature. This suggests that care must be taken when comparing even two closely related populations (Ross and Konigsberg 2002). Populations are highly variable due to the influences of environment, migration, genetics, secular change, and allometry. According to Meadows and Jantz (1995), current stature estimation formulae, developed from the contemporary population out of which forensic cases are drawn, are needed in order to accurately estimate stature in modern cases.

Sexual Dimorphism

Females are shorter on average than males in every known population (Gray and Wolfe, 1980). This difference in stature between sexes is called sexual dimorphism of stature and exists in every society. Some populations have greater variation in mean heights between the sexes than do others, however, there has been no consensus as to why this occurs. Stature is genetically defined, as is sexual dimorphism in a population. The environment in which the population lives can alter the degree of sexual dimorphism, resulting in differing degrees of sexual dimorphism between populations.

Humans have a high degree of plasticity during their development, which allows for nongenetic adjustments in stature due to stress (Stini, 1975). Humans also tend to respond to stress by modifying their growth trajectories. Greulich (1979) studied 1800 Guamanian children, and found that physical retardation and a lower degree of sexual dimorphism is common in societies that have insufficient levels of nutrition. Males are more sensitive to environmental stresses, and as a result, tend to show greater reduction in stature (Greulich, 1979). When this occurs, the gap in stature between the sexes is reduced and the population exhibits decreased levels of sexual dimorphism.

Differences exist in the amount of sexual dimorphism between populations. Both genetics and the environment play a role in the degree of sexual dimorphism and due to this, it is necessary to account for sexual dimorphism when deriving stature from human remains.

Effects of Aging on Stature

It is generally accepted that stature declines with age. According to Giles and Hutchinson (1991) it is a reasonable assumption that populations, particularly those in the United States, will begin to decrease in stature starting in their midforties. This minimal decrease begins for males at about 1 mm/year, and about 1.25 mm/year in females (Giles and Hutchinson 1991, p 767-68). This factor must be accounted for when estimating stature in an older individual, generally including people over the age of 45 (Giles 1991).

Stature estimation equations in use today require that adjustments be made to account for stature loss due to aging. Galloway (1988) found that height reduces on average by .16 cm per year after age 45. She suggests the correction of maximum height - 0.16 (age - 45), incorporated into the stature estimation equation when analyzing older individuals. Trotter (1970) states that stature decreases from year thirty by 0.06 cm per year, and recommends the equation: stature in cm - 0.06 (age – 30) cm.

Individuals who have experienced decrease in stature often do not recognize it, and will overestimate their stature. This bias in self-reported stature can be overcome with the use of measured stature, when available. Due to this trend in overestimation of self-reported stature for older individuals, it is a good idea to use both age adjusted and non-age adjusted equations for comparison against self-reported stature.

Self-report and Variation in Recorded Stature

Length measurements of long bones taken from an unidentified skeleton can be input into an equation that provides an estimate of the person's stature in life. This estimate is compared with government records or self-reported stature as part of the process to identify the individual.

There are several issues that arise with this method. First, self-reported stature has been shown to be inaccurate. The majority of people overestimate their stature. Giles and Hutchinson (1991) conducted an analysis of anthropometric data from 8000 United States Army personnel, and found that men tend to overestimate their stature by about two and a half centimeters, while women overestimate on average by about one centimeter. They also discovered that tall men and women were the most accurate with their stature, while most others tended to overestimate. Elderly individuals tend to overestimate their height more than the young. Nevertheless, Giles and Hutchingson (1991) discovered a high correlation between a person's actual height and self-reported stature.

Other issues arise when using records of living stature. Snow and Williams (1971) present an example where a single man was measured 19 times between the ages of 24 and 44 by various medical and police agencies. This is highly unusual for an individual, as most people are only measured a couple of times during life, and even less in third world countries. They found that this individual had measurements widely ranging from 157 to 170 centimeters.

Practices of recording stature in the United States tend to vary dramatically from one police precinct to another. Some accept a self-report of stature, while others will measure individuals with shoes either on or off. Some require an erect posture, while others accept a natural standing posture (Snow and Williams, 1971). If measurements at police agencies were more standardized, they would be more accurate for comparison with stature estimations from skeletal dimensions.

Measurements taken by different individuals and at different times of the day will negatively impact the accuracy of stature measurements (Snow and Williams, 1971). People tend to slump more as the day progresses, resulting in as much as an inch reduction by days end. This affects all measurements, no matter how standardized, by the police, military and medical personnel, as well as printed on driver’s licenses.

Snow and Williams (1971) provide several suggestions for improving standard measurements. They suggest using military records whenever possible, as they are more reliable, and when they are not available, medical records are the preferred choice over police records, as greater care is taken in their measuring. Finally, if multiple measurements are provided for a single individual, then the measuring techniques of the different agencies should be examined to rule out extremes and to detect the most reliable source.

Human stature is highly variable due primarily to the environments in which people live. If stature estimations are to be accurate, these variations must be considered. Accurate stature estimation from long bone measurement is particularly important in Central and South America. Stature estimation equations do not already exist for these populations, which need them most in order to identify the many unidentified human remains that exist as a result of political upheaval and relatively frequent natural disasters.

Chapter III. Materials and Methods

Materials

The data set employed in this study is from the Forensic Data Bank housed at the University of Tennessee and was provided by Dr. Richard Jantz, Director of the Forensic Anthropology Center at the University of Tennessee. The Forensic Data Bank is the product of continuous efforts by forensic anthropologists across the country to record and report data from recent populations (Ubelaker, 1998). The majority of the data comes from actual forensic cases that are recorded using standards provided by Moore-Jansen et al. (1994). David M. Glassmann of Texas State University, San Marcos, and the National Museum of Natural History provided the greater part of this data set. It consists of known living stature and maximum length of the femur and/or tibia from 24 Hispanic males (Appendix A).

Two long bone measurements were employed in this study, maximum femur length and condylo-malleolar length of the tibia. The measurements are defined as "the distance from the most superior point on the head of the femur to the most inferior point on the distal condyles" (Moore-Jansen et al., 1994 p.68) and "the distance from the superior articular surface of the lateral condyle of the tibia to the tip of the medial malleolus" (Moore-Jansen et al., 1994 p.70).

Methods

In order to assess accuracy of the various stature estimation formulae for individuals of Hispanic ancestry, these data are used in conjunction with two of the most commonly used forensic stature estimation methods today, as well as a set of equations developed from Mesoamerican cadavers. The application of the Hispanic data set to Trotter and Gleser's Korean War equations (Trotter and Gleser, 1958), as well as FORDISC (Jantz and Ousley, 1993 - 2005) and Genoves' (1967)

Mesoamerican equations allows for a comparison of the estimated and actual stature, demonstrating which equations are most accurate for estimating stature in a Hispanic population (Table 1). Descriptions of these formulae follow.

Table 1 – Stature Estimation Equations Used in this Analysis

Trotter and Gleser (Trotter 1970)	White Femur Length	Estimated stature = 2.38 (Femur length) + 61.41 ± 3.27
	White Tibia Length	Estimated stature = 2.52 (Tibia length) + 78.62 ± 3.37
	White Femur + Tibia Length	Estimated stature = 1.30 (Femur length + Tibia length) + 63.29 ± 2.99
	Mongoloid Femur Length	Estimated stature = 2.15 (Femur length) + 72.57 ± 3.80
	Mongoloid Tibia Length	Estimated stature = 2.39 (Tibia length) + 81.45 ± 3.27
	Mongoloid Femur + Tibia Length	Estimated stature = 1.22 (Femur length + Tibia length) + 70.37 ± 3.24
	Mexican Femur Length	Estimated stature = 2.44 (Femur length) + 58.67 ± 2.99
	Mexican Tibia Length	Estimated stature = 2.36 (Tibia length) + 80.62 ± 3.73
Genoves (1967)	Mesoamerican Femur Length	Estimated stature = 2.26 (Femur length) + 66.379 ± 3.417
	Mesoamerican Tibia Length	Estimated stature = 1.96 (Tibia length) + 93.752 ± 2.812
FORDISC (Jantz and Ousley, 1993 - 2005)	White Femur Length	Estimated stature = 0.101 (Femur length) + 21.29" ± 3.8
	White Tibia Length	Estimated stature = 0.096 (Tibia length) + 31.94" ± 4.0
	White Femur + Tibia Length	Estimated stature = 0.054 (Femur length + Tibia length) + 22.51" ± 3.7
	Hispanic Femur Length	Estimated stature = 0.086 (Femur length) + 28.03 ± 2.5 or 2.6
	Hispanic Tibia Length	Estimated stature = 0.054(Tibia Length) + 47.16 ± 3.8
	Hispanic Femur + Tibia Length	Estimated stature = 0.037 (Femur length + Tibia length) + 36.94 ± 3

Trotter and Gleser

Trotter and Gleser (1952) developed formulae using data from World War II male casualties of African American and Euro American descent. They used living stature measurements from the time of their induction into the military, and long bone lengths from their skeletonized remains to develop the equations (Trotter and Gleser, 1958; Trotter, 1970). The military measurements should have been conducted according to War Department Regulations as of 1944, which state that a measuring board is placed vertically behind the individual, and another board is attached by string to the first and placed firmly against the measuring rod and the top of the head. The individual should stand erect and forward without shoes, and with their back to the measuring board (Trotter, 1970). Although many different examiners measured the living stature of the individuals, the military should have used this standardized manner for measuring, so minimal inter-observer bias was expected (Trotter 1970).

Trotter alone observed the long bone measurements of the World War II data. Measurement of the twelve long bones was done using an osteometric board (Trotter, 1970). According to the definition, the bones were firmly placed lengthwise between the blocks of the osteometric board and moved up and down slightly to ensure that the maximum length was measured. The measurements were conducted from the head or lateral condyle, to the most distal portion, or malleolus.

Trotter and Gleser (1952) also analyzed civilian cadavers from Washington University School of Medicine and found that the average cadaver was approximately 2.5 centimeters taller than the average sampled living stature. They did this by comparing their average cadaver stature with that of a random sample from a living population. They concluded that it was reasonable to expect greater stature when measuring cadaver length, and incorporated this 2.5 centimeter adjustment into their calculations of living stature from cadaver length.

Trotter and Gleser (1958) reevaluated their original formulae using casualties from the Korean War. This sample contained a more ethnically diverse group of individuals including Mongoloid, Mexican, Puerto Rican, Euro American and African American males. The Mongoloid groups include Japanese, Hawaiians, Filipinos, and Native Americans (Trotter, 1970 p.82). The Mongoloid and Mexican data are relatively small and heterogeneous, and so are subject to greater sampling error.

According to Jantz and coworkers (1994, 1995), it appears that Trotter neglected to measure the medial malleolus of the tibia in her analysis of the World War II and Terry collections. However, she did not measure the Korean War long bones herself, and instead sent directions for their measurement, which included the malleolus, to technicians. It would appear that the Korean War data and equations are likely to be more accurate than those from WWII, so the American White and Black, as well as the Mongoloid and Mexican equations from the Korean War will be used in this analysis.

FORDISC

FORDISC (Jantz and Ousley, 1993 - 2005) is a computer program that allows forensic anthropologists to classify unknown adults based on known samples (Ubelaker, 1998). The latest version, FORDISC 3.0, uses discriminant functions to estimate sex and ancestry and provides regression formulae to estimate stature. This program offers stature formulae for use with multiple different combinations of long bone measurements, which is particularly advantageous in the case of a partial skeleton (Ubelaker, 1998). These measurements include the maximum length of the femur, tibia, fibula, humerus, radius and ulna. All measurements should be conducted using an osteometric board where their entire length is measured (Moore-Jansen et al, 1994). For example, the tibia is measured from the lateral condyle to the tip of the medial malleolus. Other measurements can be used as well, such as the maximum epiphyseal breadth of the proximal tibia, and the transverse diameter of the tibia at the nutrient foramen. Other bones can also be used with this method, including the clavicle, sacrum, and calcaneus. This variety of bones and measurements is useful in forensic cases where only partial remains are found and identification is difficult; however, using long bone lengths should prove most accurate with this method of analysis as well.

This interactive computer system was created primarily using data from the Forensic Data Bank at the University of Tennessee, a compilation of skeletal data provided by professionals around the country from modern populations. The stature estimation equations provided by FORDISC, based on the Forensic Data Bank and the Trotter and Gleser formulae, are the most commonly used in forensic anthropology today. This analysis will include American White and Hispanic stature estimation equations from FORDISC. The Hispanic equations were derived from the Forensic Data Bank and are based on the same data set used in this analysis. These equations will be useful in identifying the maximum degree of accuracy possible for this data.

Genoves

Genoves (1967) took the measurements of 280 cadavers, lying supine, from the National School of Medicine, which had been obtained from hospitals throughout the Federal District of Mexico. He adjusted living stature to account for the extended length of the cadavers by adding 2.5 cm to total stature, as recommended by Trotter

(1970). He also measured their dried long bone lengths and measured the femur, the tibia (without the tuberosity), and the fibula, humerus, ulna and radius (Genoves, 1967). The majority of the bodies obtained for study were generally from the lower socioeconomic class, which in Mexico typically means they have the greatest proportion of American Indian ancestry. Out of the equations examined, these equations should most accurately represent an indigenous Hispanic population.

When the Hispanic data set is applied to the stature estimation equations developed by Genoves, a more accurate estimation should result, compared to the Trotter and Gleser and the FORDISC equations, with the exception of the FORDISC Hispanic equations. This is because Genoves used a sample from a more recent population than those of Trotter and Gleser and is also from a Hispanic population.

Analysis

In order to show that the most accurate stature estimation methods use a reference sample that is representative of the questioned population, data from Hispanic men were applied to 16 equations. These equations derive from the Trotter and Gleser Korean War data analysis, as well as FORDISC and Genoves' Mesoamerican equations. Trotter and Gleser's American White, American Black, Mongoloid and Mexican equations from the Korean War (Trotter, 1970) were chosen due to the mismeasure of the tibia in their WWII analysis. Genoves' (1967) Mesoamerican equations and FORDISC's American White and Hispanic male equations were also employed.

The estimation formulae are produced by linear regression, typically in the format of $y = mx + b$, where Y is the stature, X is the long bone measurement, M is the slope and B is the intercept (Giles and Klepinger, 1988). After each equation is the plus-minus number called the standard error of estimate. This number, when added or subtracted from Y, will give a range into which the true living stature should fall. This was done using a 95% confidence interval. FORDISC's Hispanic femur equation was the only equation with a variable confidence interval. If the maximum femur length was longer than 472 millimeters, the confidence interval was 2.6 centimeters, and if it was shorter, the confidence interval was 2.5 centimeters (See Table 1).

Adjustments to the data were necessary in order to make the results of the equations comparable. For example, the long bone measurements for the Trotter and Gleser and Genoves equations were multiplied by 0.1 to convert the data to centimeters, as required by the equations. The results from the FORDISC equations were also altered, dividing them by 0.3937 to change the estimated stature from inches to centimeters. To account for live stature in the Genoves equations, 2.5 centimeters was subtracted from the estimated stature, because his original measurements were of cadavers. Due to the very small number of individuals with known age, and in particular age over 30, adjustments were not made for reduction in stature with age to any of the equations.

For this study only equations with the tibia, femur or both, were chosen because these correlate best with stature (Genoves, 1967; Trotter, 1970). Bones from the left side of the body were utilized because research has not identified a significant difference between the two (Genoves, 1967; Trotter and Gleser, 1958). However, if a bone was missing from the left side and there was data from the right side, the right side was used.

In order to determine if in fact a stature estimation equation, similar ethnically to the sample, provided the most accurate estimation, the Hispanic data was applied to each of the equations and calculated the mean estimated stature, as well as the high and low to show the range. To test the degree of error and bias I calculated inaccuracy using the equation $\Sigma |(\text{estimated stature} - \text{known stature})| /n$, and bias using the equation $\Sigma(\text{estimated stature} - \text{known stature})/n$.

I also conducted a paired t-test using known stature and the stature estimates for each individual. A paired t-test is used to compare the means of two groups (Landau and Everitt, 2004). This will identify if there is a significant difference between the known and estimated statures, and may indicate which equations are most accurate for this data set. In this case it would be expected that the Genoves and FORDISC Hispanic data would be most accurate for this data set.

In order to identify the degree of linear association between the known stature and the estimated mean stature from each equation, a Pearson's correlation was conducted. This correlation analysis involved the known stature and the estimated stature provided by the formulae. If the correlation is relatively high, above 0.5, then the estimation and known stature have a high linear association. Correlations do not always provide an accurate visual representation of how the variables relate to each other, so I have created scatter plots of the mean estimated stature against the known stature for each equation (Figures 1-16). It is expected that FORDISC's Hispanic equations and Genoves' equations would correlate best with the data set. The Hispanic equations were developed from this data set, so should be highly correlated, and the Genoves equations are from a similar ethnic sample as the data set, assuming the data set is made of recent immigrants from Latin America. These tests were conducted using SPSS 14.0, the Statistical Package for the Social Sciences, which allows for the manipulation and analysis of data (SPSS Inc., 2005).

My null hypothesis is that the estimated and the known statures for each equation are equal. My alternate hypothesis is that the estimated and the known statures for each equation are different. I can either accept or reject my null hypothesis according to the results of my paired t-test and Pearson’s correlation.

IV. Results

Applying the data to the Trotter and Gleser, FORDISC and Genoves equations, as well as calculating the standard error, allows for comparison between the equations. It also allows for assessment of accuracy for estimating living stature in a Hispanic population, and identification of the direction in which inaccuracy lay. Table 2 shows the average inaccuracy and average bias for each equation. Appendix B shows the individual mean, high, low, inaccuracy and bias for each equation.

The equations with the greatest inaccuracy and largest bias include both of the Trotter and Gleser equations with the femur and tibia added together, as well as the Genoves equations. The Trotter and Gleser and FORDISC American White male femur, and FORDISC Hispanic male femur equations are the most accurate and had the least amount of bias. These results suggest that the Trotter and Gleser, and FORDISC American White male femur equations, and the FORDISC Hispanic male femur equation, are the most accurate in estimating this Hispanic data set. Genoves' Mesoamerican equations and the combined femur and tibia equations from Trotter and Gleser are some of the most inaccurate for this data set. All of the equations that include the tibia appear to have wide ranges both for inaccuracy and bias, as well as larger inaccuracy values.

Table 3 provides a key for reading Figures 1 through 3 and Table 4. Figures 1 through 3 give a visual representation of the range of bias that exists in each of the equations. These figures are organized according to the long bone used in the equation.

Figures 1 through 3 suggest that the Genoves equations tend to consistently underestimate actual stature, followed by Trotter and Gleser's Mexican male equations. Trotter and Gleser's and FORDISC's American White tibia equations also appear to regularly overestimate stature. The equations with the least amount of bias appear to be Trotter and Gleser's American White and Mongoloid, and FORDISC's American White and Hispanic equations for the femur. Trotter and Gleser's Mexican and Mongloid equations appear to hold the least amount of bias for the tibia equations. Finally, the Trotter and Gleser combined femur and tibia equations show greater bias, than do the FORDISC combined femur and tibia equations. Overall, the equations that involve the femur appear to be the most accurate, so these equations will be analyzed further.

Table 2 – Average Inaccuracy and Bias

Author	Equation	Average Inaccuracy	Inaccuracy Range	Average Bias	Bias Range
Trotter and Gleser (1952, 1958)	White Femur Length	1.88	0.03 - 8.30	0.14	-8.3 - 6.02
	White Tibia Length	4.11	.06 - 21.21	1.36	21.21 - 11.28
	White Femur + Tibia Length	9.29	1.68 - 18.80	-9.29	-18.80 - -1.68
	Mongoloid Femur Length	1.89	0.17 - 8.89	-0.5	-8.89 - 5.26
	Mongoloid Tibia Length	3.65	0.43 - 22.50	-0.24	-22.50 - 9.62
	Mongoloid Femur + Tibia Length	7.82	0.23 - 17.27	-7.82	-17.27 - -0.23
	Mexican Femur Length	2.31	0.11 - 9.77	-1.3	-9.77 - 4.67
	Mexican Tibia Length	3.88	0.28 - 24.13	-2.18	-24.13 - 7.60
Genoves (1967)	Mesoamerican Femur Length	4.5	1.42 - 12.65	-4.22	-12.65 - 1.61
	Mesoamerican Tibia Length	6.62	1.38 - 24.22	-6.4	-24.22 - 2.48
FORDISC (Jantz and Ousley, 1993 - 2005)	White Femur Length	2.04	0.01 - 8.74	-0.23	-8.74 - 5.88
	White Tibia Length	4.06	0.18 - 21.52	-1.24	0.18 - 11.20
	White Femur + Tibia Length	2.97	0.18 - 8.49	-0.38	-13.85 - 8.17
	Hispanic Femur Length	1.88	0.31 - 8.72	-0.32	-8.72 - 5.46
	Hispanic Tibia Length	3.92	0.12 - 11.45	0.3	-11.45 - 7.83
	Hispanic Femur + Tibia Length	2.94	0.16 - 7.99	0.73	-7.73 - 7.99

Table 3 – Key for Abbreviations

Equation	Abbreviation
Trotter and Gleser White Femur	TGWF
Trotter and Gleser White Tibia	TGWT
Trotter and Gleser White Fem+Tib	TGWFT
Trotter and Gleser Mongoloid Femur	TGMF
Trotter and Gleser Mongoloid Tibia	TGMT
Trotter and Gleser Mongoloid Fem+Tib	TGMFT
Trotter and Gleser Mexican Femur	TGMeF
Trotter and Gleser Mexican Tibia	TGMeT
FORDISC White Femur	FWF
FORDISC White Tibia	FWT
FORDISC White Fem+Tib	FWFT
FORDISC Hispanic Femur	FHF
FORDISC Hispanic Tibia	FHT
FORDISC Hispanic Fem+Tib	FHFT
Genoves Mesoamerican Femur	GMF
Genoves Mesoamerican Tibia	GMT

Figure 1 – Bias in Femur Equations

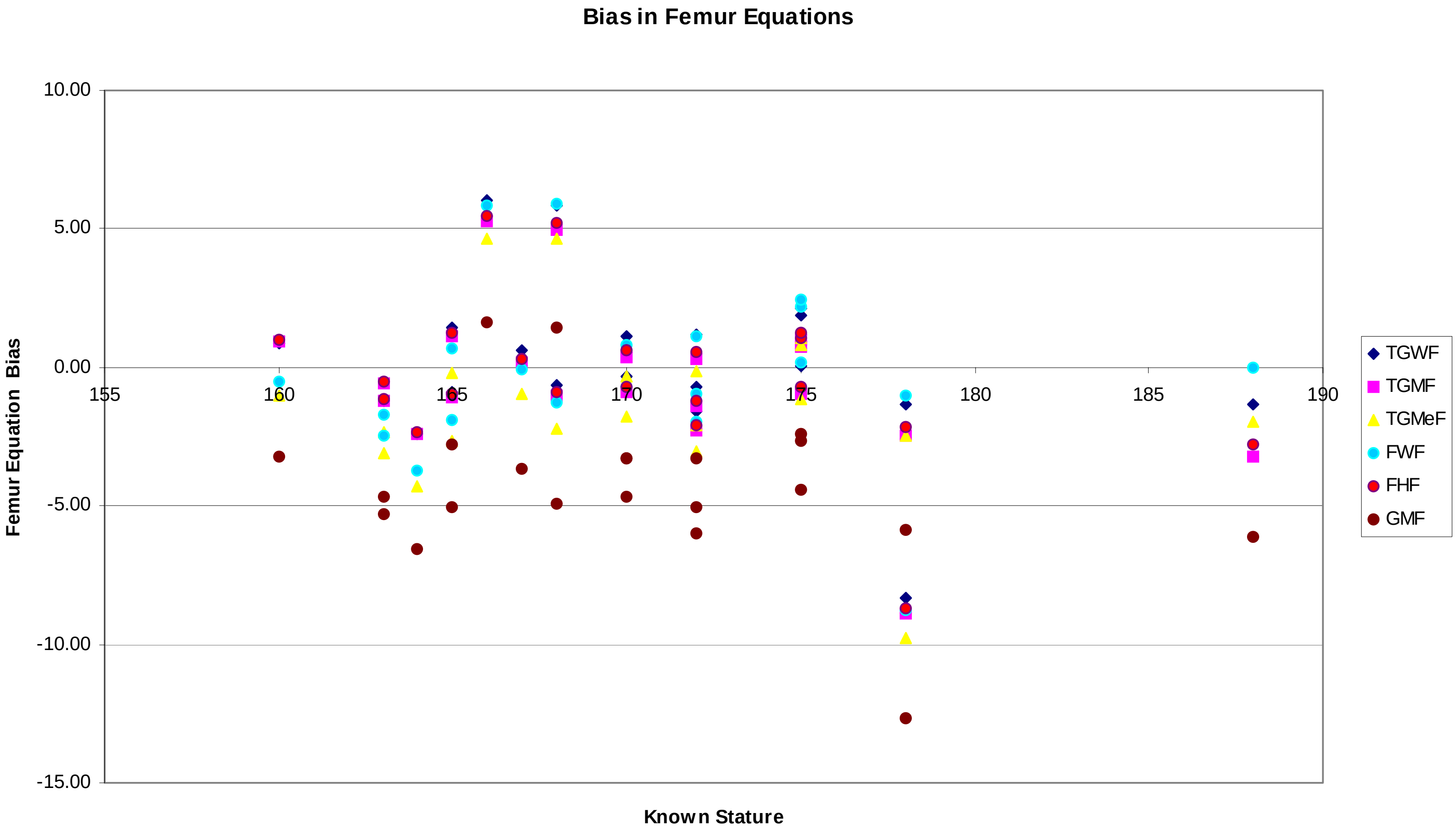


Figure 2 – Bias in Tibia Equations

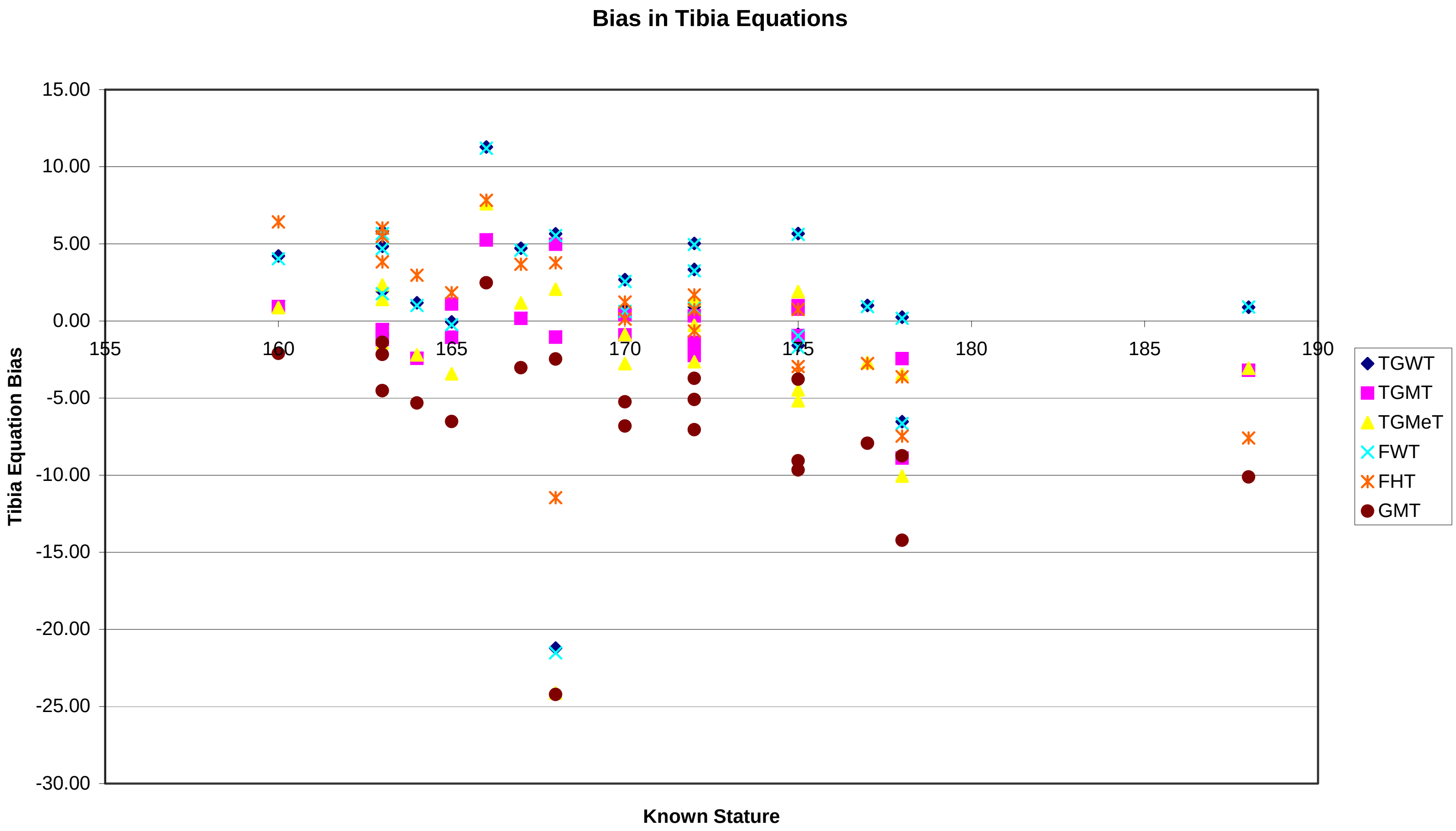
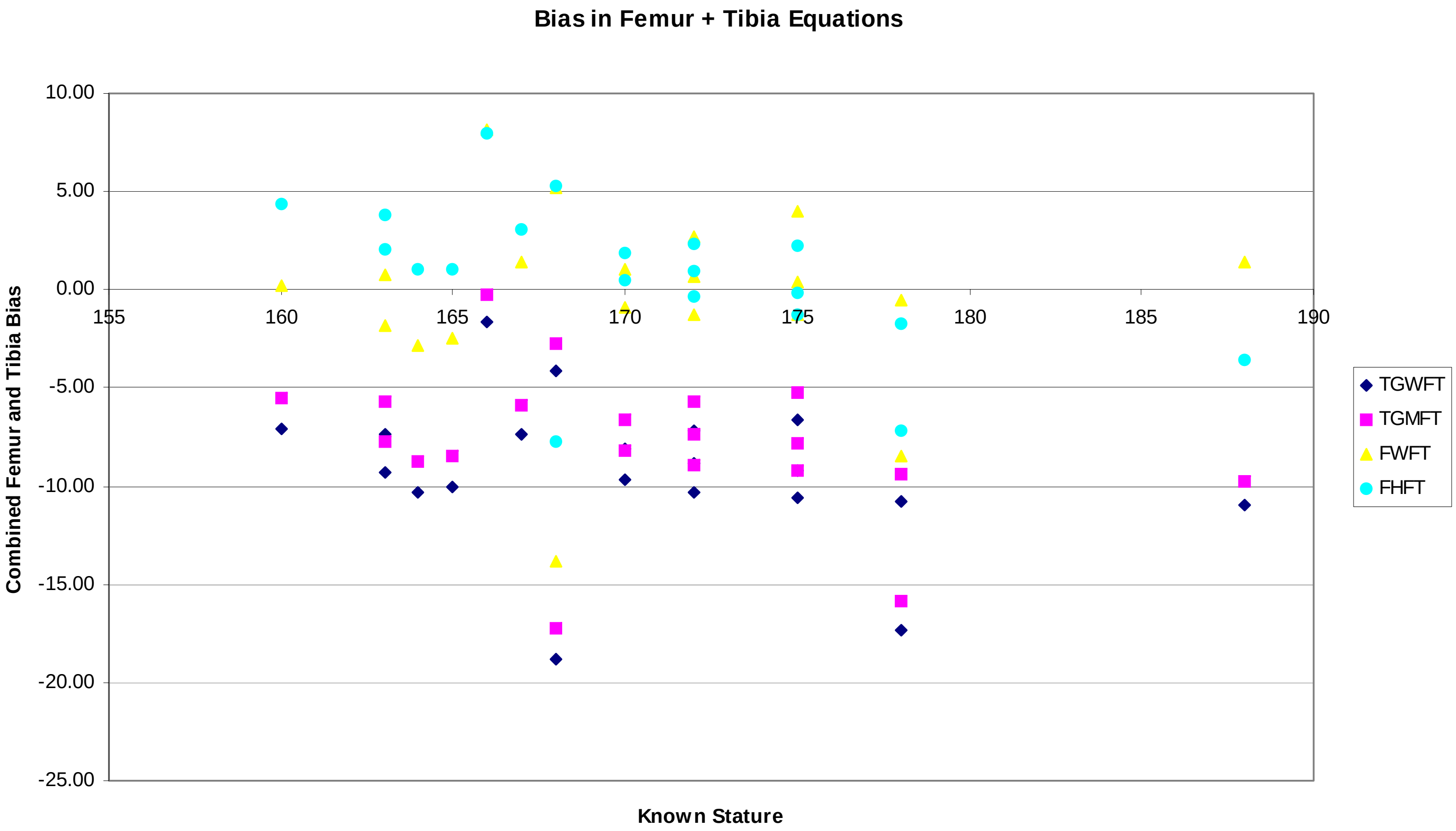


Figure 3 – Bias in Femur + Tibia Equations



Paired t-tests of the estimated stature from each equation against known stature revealed no significant difference between the estimate and known stature for the majority of the equations. Table 4 provides the results of the paired t-tests. I set my predetermined alpha at 0.05, to generate a 95% confidence interval. The two-tailed significance numbers are of particular interest, as those with p-values below 0.05 indicated that the estimated statures are significantly different from the known stature. These include Trotter and Gleser's Mexican femur equation, Genoves' equations and Trotter and Gleser's combined femur and tibia equations for both American Whites and Mongoloids. Those equations with significant p-values produced estimates significantly different from known stature. Those with p-values that were not significant, produced mean estimates that were not significantly different from known stature. These include the Trotter and Gleser American White male femur and FORDISC's American White femur equations. These results suggest that the equations using both the femur and the tibia provide poor estimations of stature for this data set, as indicated by the significant t-test p-values. The Genoves equations also have significant p-values, suggesting that they as well provide stature estimations significantly different from known stature for this data set.

Table 4 – Paired Samples T-Test Results

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	knownstature - TGWF	-.13818	2.84290	.60611	-1.39865	1.12229	-.228	21	.822
Pair 2	knownstature - TGWT	-1.35864	6.15563	1.31239	-4.08789	1.37062	-1.035	21	.312
Pair 3	knownstature - TGWFT	9.29000	3.80151	.85004	7.51084	11.06916	10.929	19	.000
Pair 4	knownstature - TGMF	.49727	2.80188	.59736	-.74501	1.73956	.832	21	.415
Pair 5	knownstature - TGMT	.23545	6.09727	1.29994	-2.46792	2.93883	.181	21	.858
Pair 6	knownstature - TGMFT	7.81850	3.79717	.84907	6.04137	9.59563	9.208	19	.000
Pair 7	knownstature - TGMeF	1.30045	2.91544	.62157	.00782	2.59309	2.092	21	.049
Pair 8	knownstature - TGMeT	2.17909	6.03727	1.28715	-.49768	4.85586	1.693	21	.105
Pair 9	knownstature - FWF	.23182	3.02709	.64538	-1.11032	1.57396	.359	21	.723
Pair 10	knownstature - FWT	-1.23955	6.19201	1.32014	-3.98493	1.50584	-.939	21	.358
Pair 11	knownstature - FWFT	.37900	4.62445	1.03406	-1.78531	2.54331	.367	19	.718
Pair 12	knownstature - GMF	4.22273	2.82077	.60139	2.97207	5.47339	7.022	21	.000
Pair 13	knownstature - GMT	6.39636	5.38045	1.14712	4.01080	8.78192	5.576	21	.000
Pair 14	knownstature - FHF	.31909	2.80406	.59783	-.92416	1.56234	.534	21	.599
Pair 15	knownstature - FHT	-.29500	4.94055	1.05333	-2.48552	1.89552	-.280	21	.782
Pair 16	knownstature - FHFT	-.73288	3.81245	.85249	-2.51716	1.05140	-.860	19	.401

Examination of the Pearson's correlation, which depicts the relationship between the estimated and known stature for each equation, reveals that all of the equations have a strong linear relationship between these two values (Table 5). All of the equations have high correlation and a significant p-value. This may indicate that the estimates may have a high correlation, but may not accurately estimate the data. Due to this, scatter plots of estimated stature against known stature, with best-fit lines are included to provide a graphical representation of the data (Figures 3-19). These plots show a general linear trend with few outliers. This suggests that high correlation values are generally a good representation of the data.

The equations with the greatest inaccuracy and bias are Trotter and Gleser's combined femur and tibia equations and both of Genoves' equations. The most accurate equations with the least bias are Trotter and Gleser's and FORDISC's American White male femur equations, as well as FORDISC's Hispanic femur equation. The paired t-test showed that there was a significant difference between known stature and the estimates from Genoves' equations, and Trotter and Gleser's Mexican femur equation. The equations involving the tibia are the most inaccurate and present the greatest inaccuracy and bias ranges, where as the femur equations provide the most accurate estimations of stature. However, all of the equations showed strong correlations with known stature.

Table 5 – Correlations Between Known Stature and Stature Estimates

Stature Estimation Equations	Correlation with Known Stature	P-Value
Trotter and Gleser White Femur	0.899	0.000
Trotter and Gleser White Tibia	0.668	0.001
Trotter and Gleser White Fem+Tib	0.832	0.000
Trotter and Gleser Mongoloid Femur	0.898	0.000
Trotter and Gleser Mongoloid Tibia	0.668	0.001
Trotter and Gleser Mongoloid Fem+Tib	0.83	0.000
Trotter and Gleser Mexican Femur	0.899	0.000
Trotter and Gleser Mexican Tibia	0.668	0.001
FORDISC White Femur	0.898	0.000
FORDISC White Tibia	0.668	0.001
FORDISC White Fem+Tib	0.816	0.000
FORDISC Hispanic Femur	0.899	0.000
FORDISC Hispanic Tibia	0.668	0.001
FORDISC Hispanic Fem+Tib	0.816	0.000
Genoves Mesoamerican Femur	0.898	0.000
Genoves Mesoamerican Tibia	0.668	0.001

Figure 4 – Trotter and Gleser’s White Male Femur Equation Scatter Plot

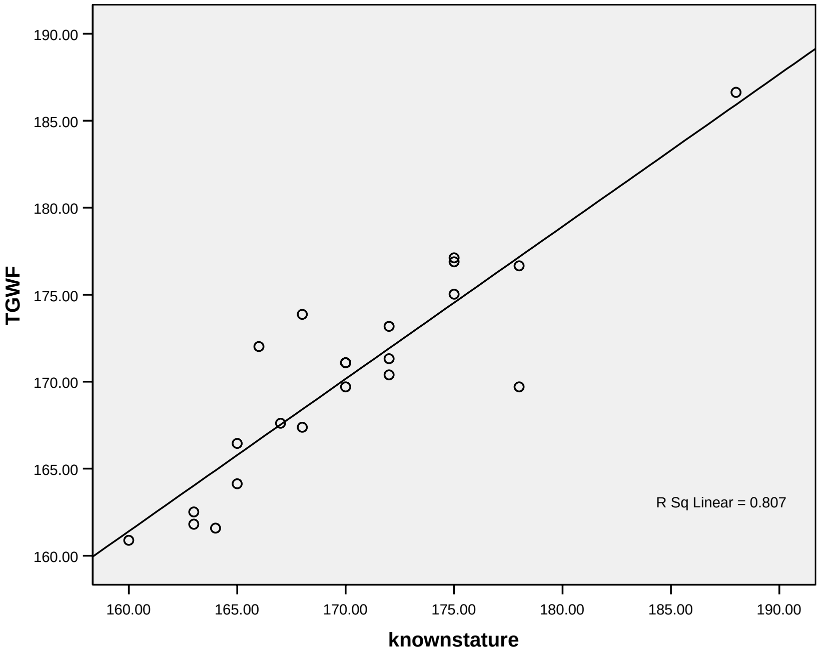


Figure 5 – Trotter and Gleser’s White Male Tibia Equation Scatter Plot

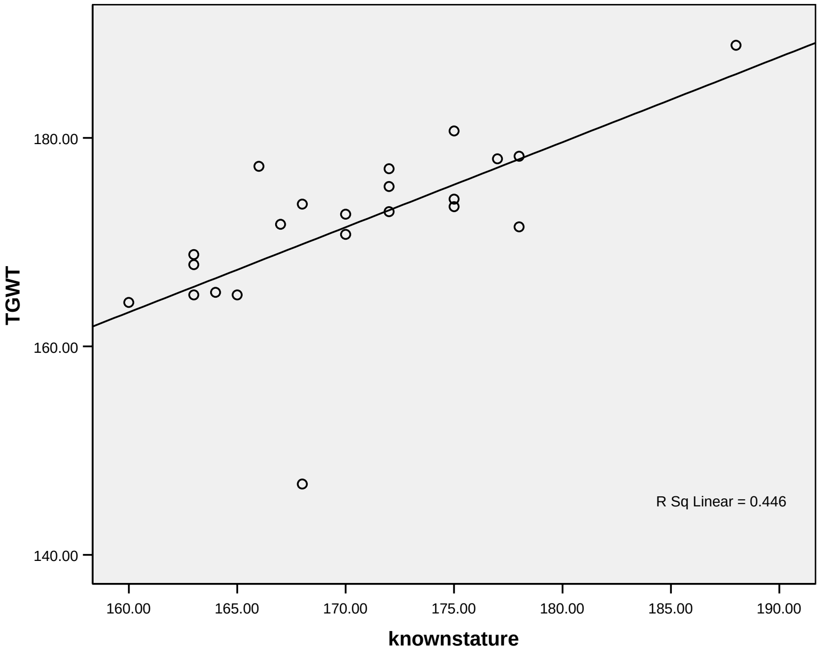


Figure 6 – Trotter and Gleser's White Male Femur + Tibia Equation Scatter Plot

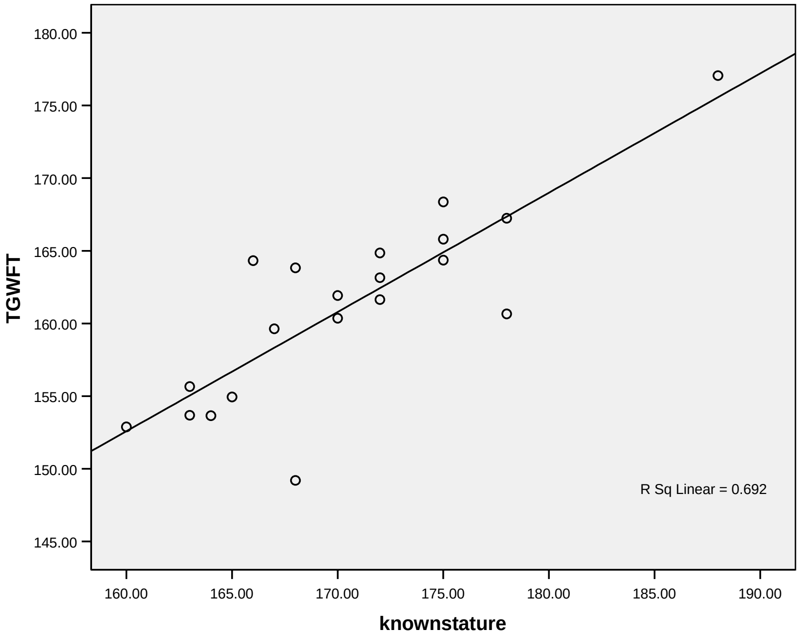


Figure 7 – Trotter and Gleser's Mongoloid Male Femur Scatter Plot

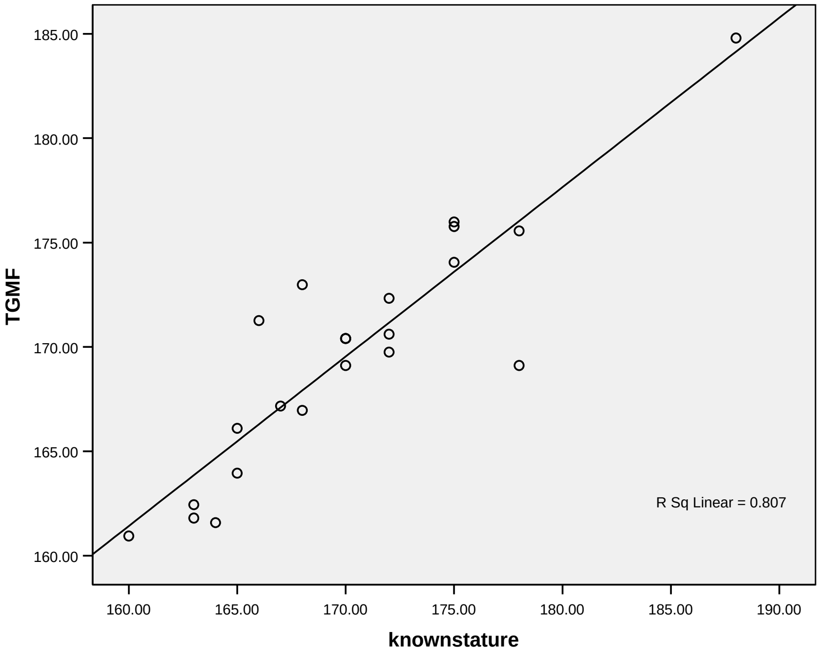


Figure 8 – Trotter and Gleser's Mongoloid Male Tibia Equation Scatter Plot

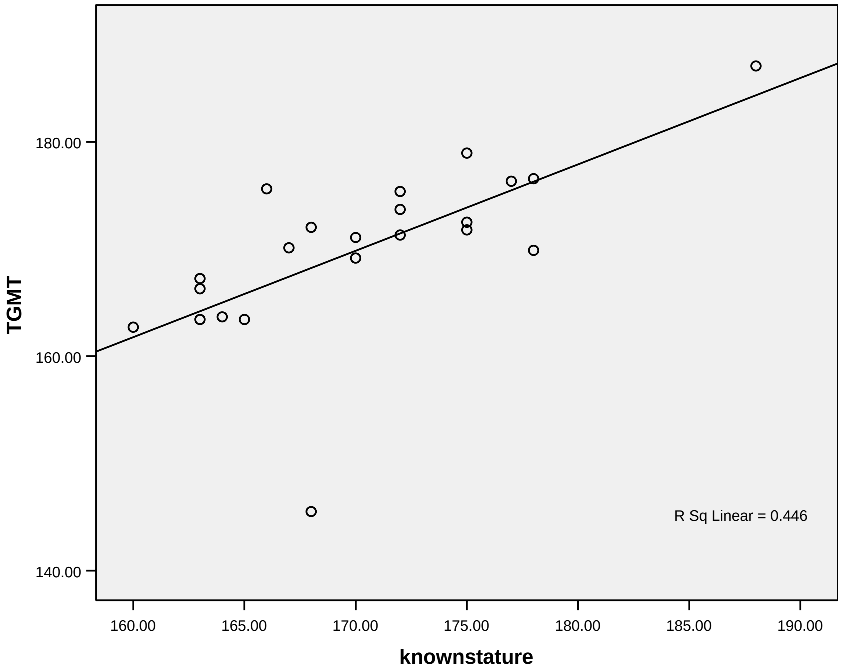


Figure 9 – Trotter and Gleser's Mongoloid Male Femur + Tibia Equation Scatter Plot

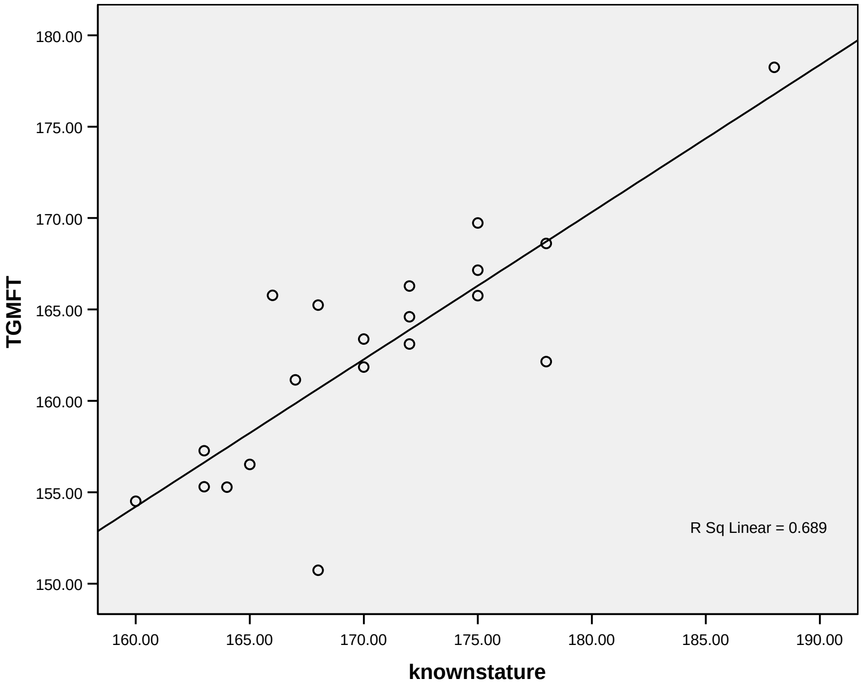


Figure 10 – Trotter and Gleser's Mexican Male Femur Equation Scatter Plot

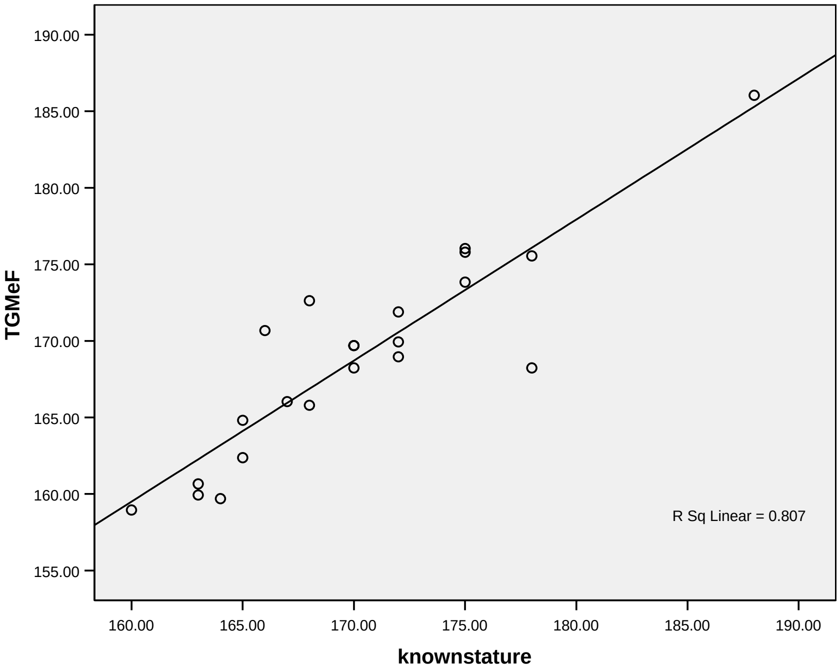


Figure 11 – Trotter and Gleser's Mexican Male Tibia Equation Scatter Plot

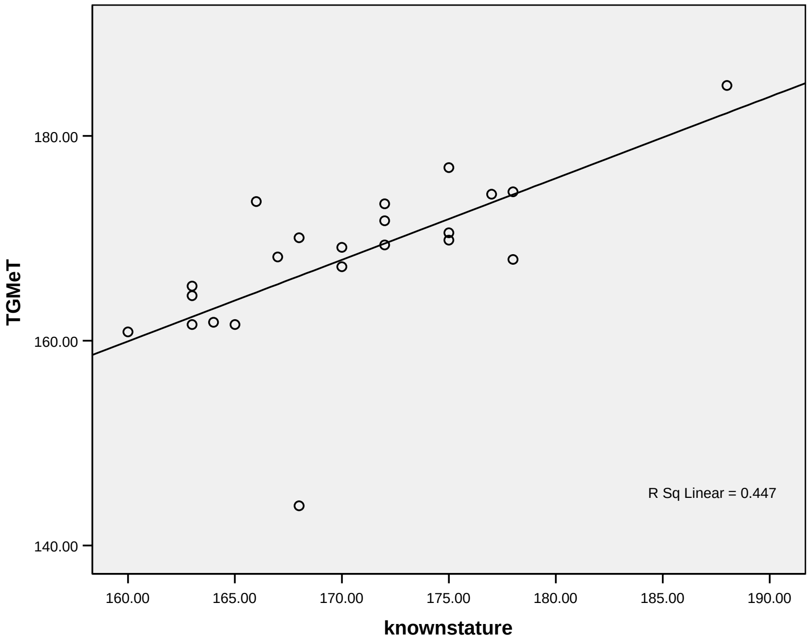


Figure 12 – FORDISC's White Male Femur Equation Scatter Plot

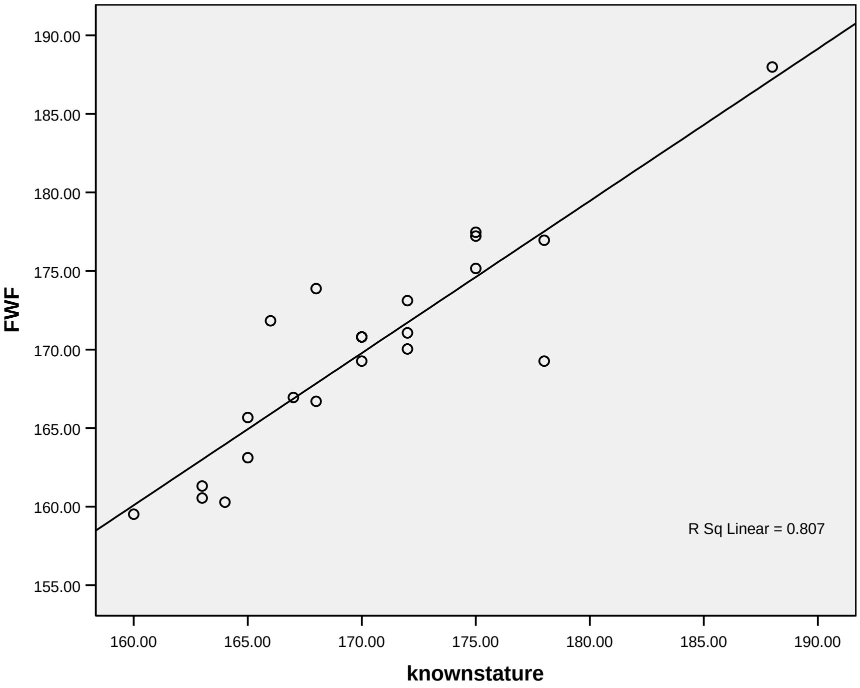


Figure 13 – FORDISC's White Male Tibia Equation Scatter Plot

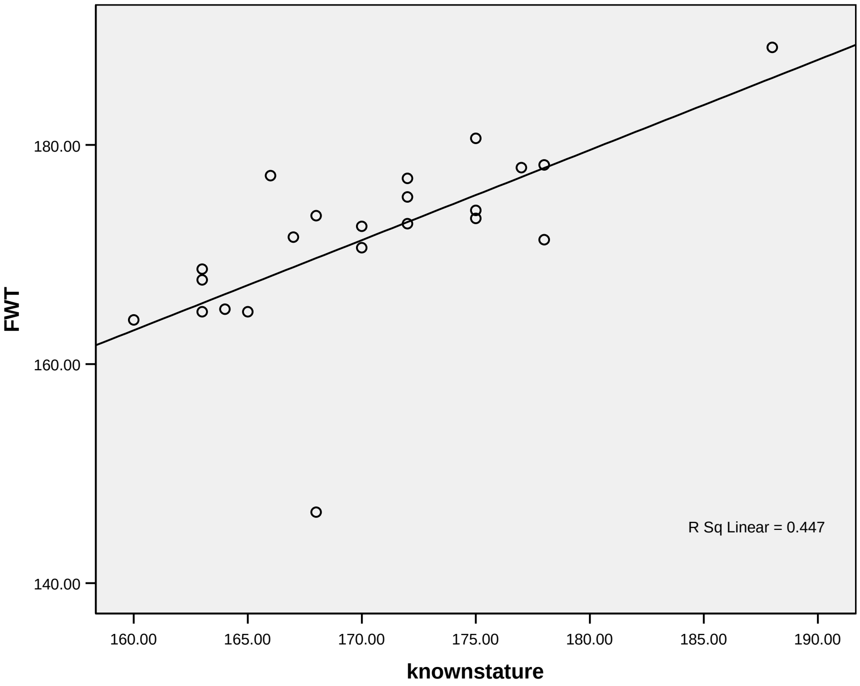


Figure 14 – FORDISC's White Male Femur + Tibia Equation Scatter Plot

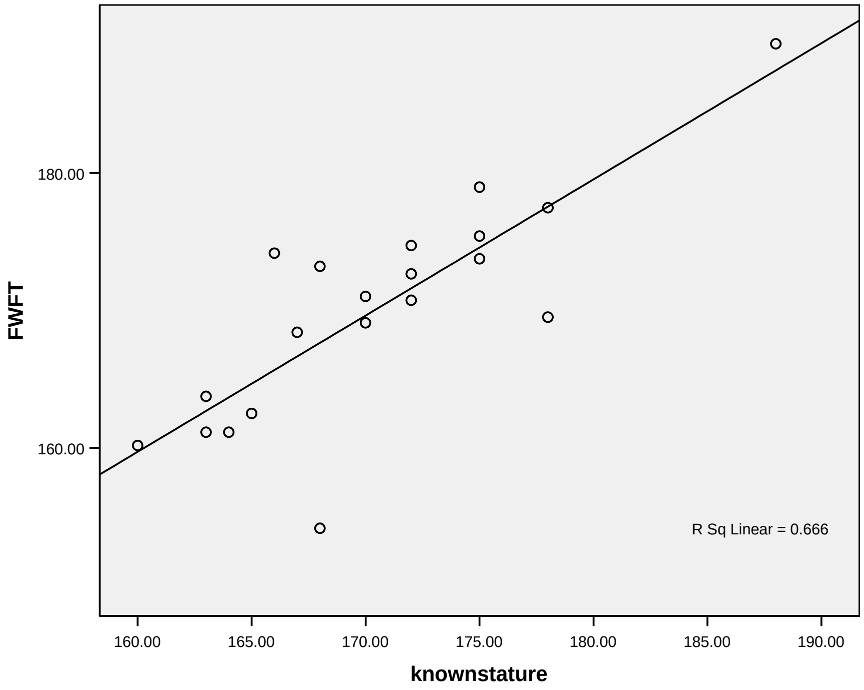


Figure 15 – FORDISC's Hispanic Male Femur Equation Scatter Plot

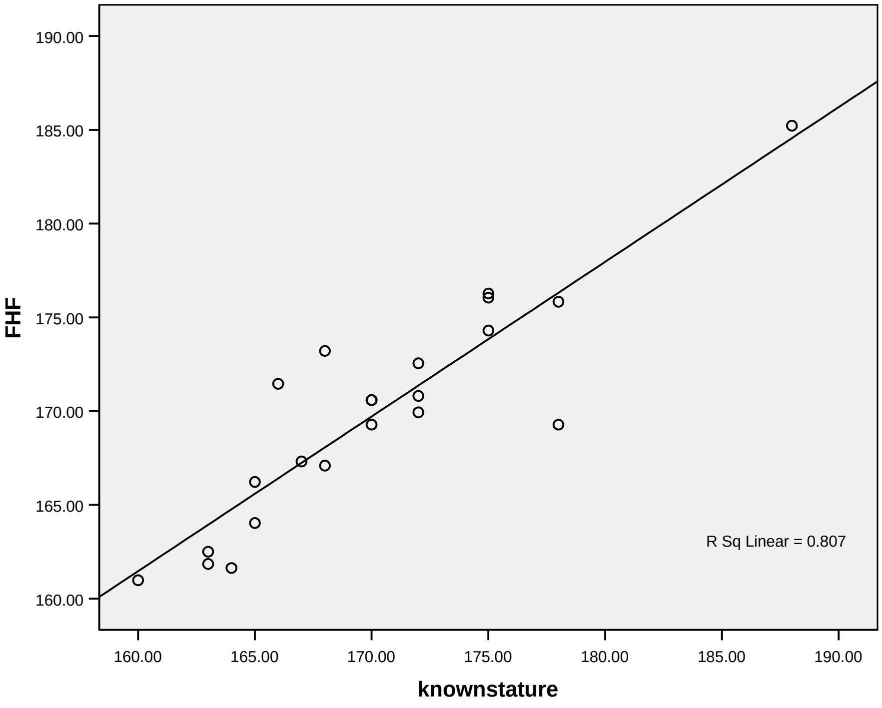


Figure 16 – FORDISC's Hispanic Male Tibia Equation Scatter Plot

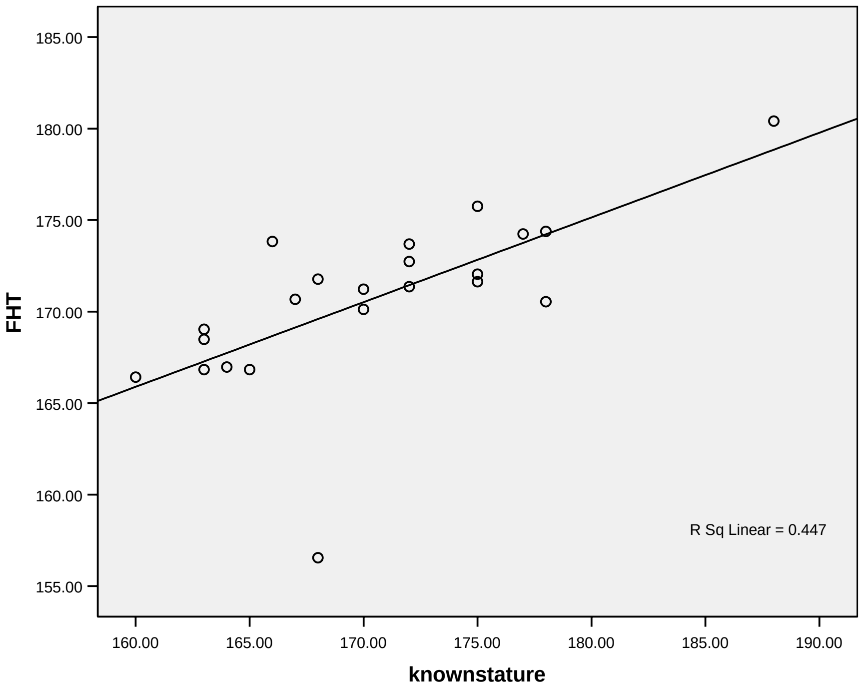


Figure 17 – FORDISC's Hispanic Male Femur + Tibia Equation Scatter Plot

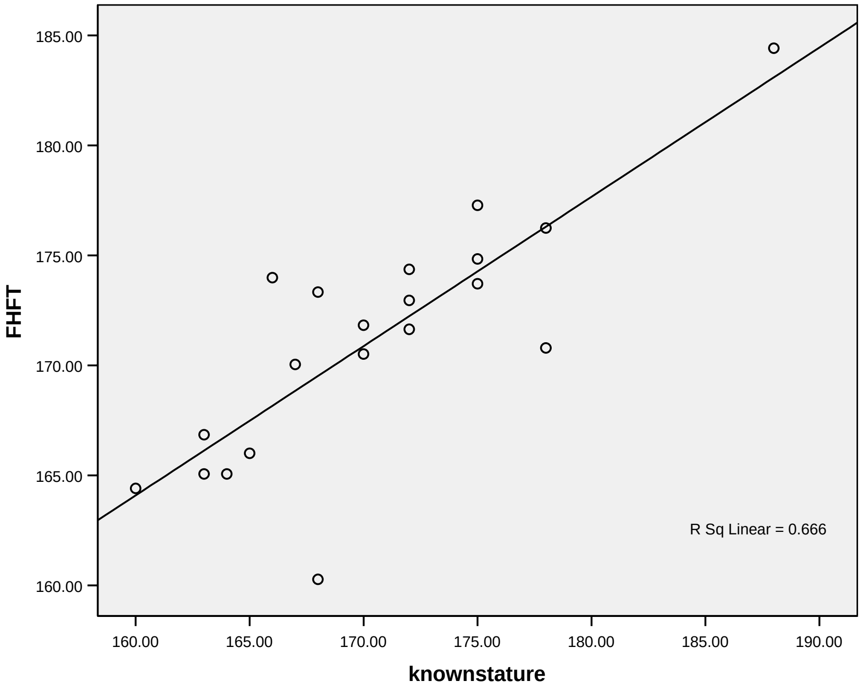


Figure 18 – Genoves' Mesoamerican Femur Equation Scatter Plot

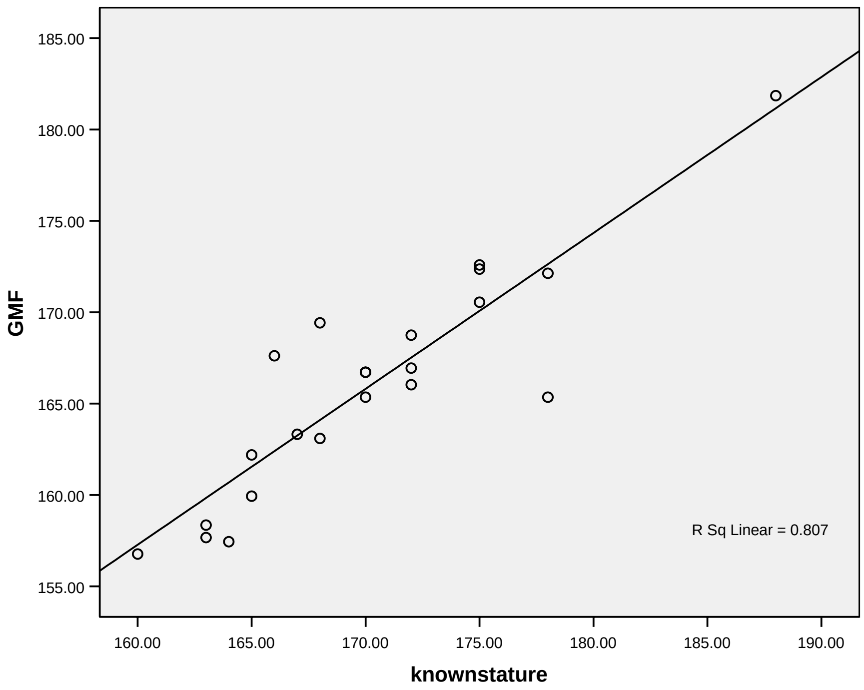
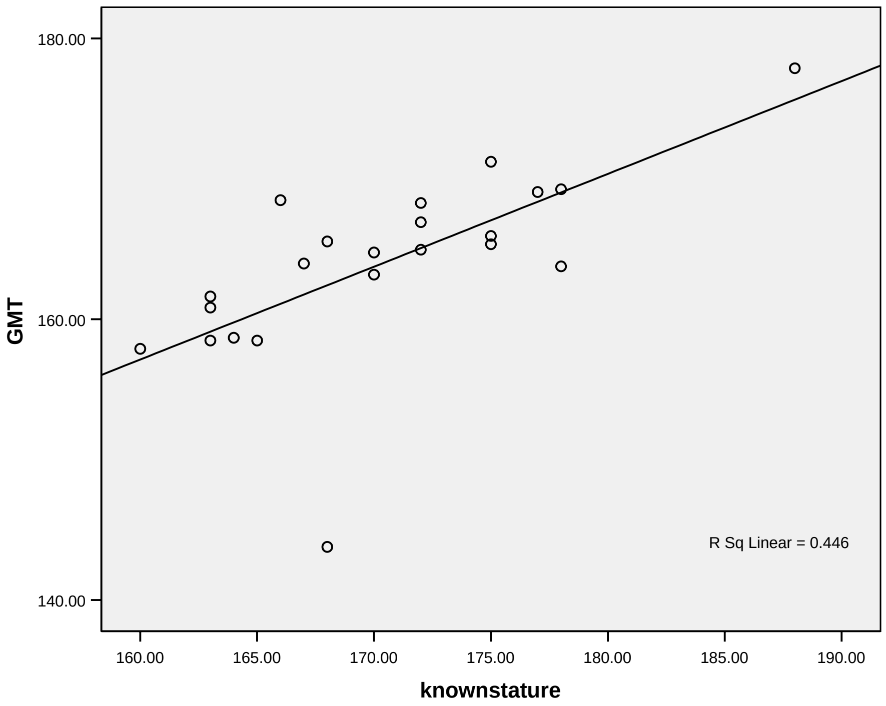


Figure 19 – Genoves' Mesoamerican Tibia Equation Scatter Plot



V. Discussion

Some patterns have emerged in the analysis of this data that must be discussed. For example, the equations made up of both the femur and the tibia, have the greatest inaccuracy and the largest bias. These combined femur and tibia equations provided by Trotter and Gleser, and significant t-test p-values, suggests that their estimates are significantly different from known stature. The combined femur and tibia equations do not appear to be as accurate as using a single bone, and certainly do not represent the Hispanic data set well.

The FORDISC Hispanic equations were relatively high in accuracy, low in bias, and the estimated and actual statures are not significantly different. This is as expected given that this equation was developed from the data set from which it was derived and these estimates represent the maximum degree of accuracy for this data set.

The Genoves equations appear to have some of the greatest inaccuracy and largest bias values among all of the equations. They also have significant t-test p-values, which suggest that the stature estimates differ significantly from known stature. Genoves derived his data set from measurements of cadavers from the National School of Medicine, which had been obtained from hospitals throughout the Federal District of Mexico. This selection is typically of the poorest segment of society, which generally includes Mexican Natives whose stature has been affected by their poor environment. Differing environments could be one reason why these equations produce dissimilar statures estimations compared with known stature. Another possibility is that because he took measurements of cadavers, Genoves subtracted 2.5 centimeters from his estimations, as prescribed by Trotter and Gleser, to generate a living stature estimate. However, Trotter and Gleser developed this adjustment from a very different population, which could account for the consistent underestimation of this equation for the data set.

Yet another possible reason why Genoves' equations did not provide accurate estimations of stature for the Hispanic data set, is that there is no way to tell if the Hispanic sample is similar to the sample Genoves used. What is Hispanic? Many cultures consider themselves Hispanic, ranging from Mexico, to Argentina and Spain. This Hispanic data derives from the Forensic Data Bank and is made up in large part of cases from David M. Glassmann at Texas State University, San Marcos and the National Museum of Natural History. It would be difficult to identify from what country each individual originated, as well as if these people are recent immigrants, or long-term residents of the United States who have experienced generations of admixture.

Trotter and Gleser's Mexican equations may also be expected to provide estimates similar to known stature, however they also have high bias and inaccuracy values, as well as wide inaccuracy and bias ranges. The Mexican equations would appear to be poor estimators of this data set. Trotter and Gleser (1958) warned that their Mongoloid and Mexican equations were derived from small and heterogeneous data samples, so were subject to greater sampling error. This suggests that these equations are not large enough to provide reliable results.

While the Hispanic equations have provided understandably accurate estimates, the Genoves and Mexican equations do not provide the results that are expected. This could be because none of the equations, except of course the Hispanic equations, are truly representative of the sample population. Ross and Konigsberg (2002) created new stature estimation formulae for Eastern Europeans when they discovered that Trotter and Glesers' Euro American and African American equations systematically underestimated stature for this population. Their primary reason for creating these formulae was the allometric variation discovered within populations of European ancestry (Ross, 2000). While Trotter and Gleser warned against using their equations on populations unrelated to the samples from which the equations were drawn, this population is very similar in theory to the sample the authors used for their American White equations. This suggests that these equations have a very narrow range of individuals onto which they can be applied.

As many other researchers have discovered, there simply aren't enough equations today to account for the degree of variation exhibited in humans. Ross and Konigsberg (2002) were forced to develop their own equations when they discovered that limb proportions contributed significantly to their population differing appreciably from Trotter and Gleser's American White equations. Komar (2003) reported on the attempt by anthropologists in Srebrenica to identify thousands of male Muslims who were victims of war. These anthropologists discovered an almost complete inability to identify these individuals due to the absence of antemortem data on stature or other identifying characteristics, as well as stature estimation equations that were not created for this population and were inadequate for its estimation.

Meadows Jantz and Jantz (1999) also discovered secular change in size and changes in limb proportions due to environmental forces, including disease and nutrition, make old equations obsolete. Older equations must be adapted, or new equations created to account for the trends observed today.

Wars, natural disasters and human rights atrocities leave vast numbers of unidentified bodies, which without better methods of identification will remain unidentified. South and Central America in particular, frequently experience political unrest and human rights abuses that claim the lives of many of the poor. These people are not represented as a population in stature estimation equations. Without the help of dedicated scientists, developing stature estimation equations for more populations and other methods of identification, these people have little hope of being identified and returned to their families.

VI. Conclusion

The present analysis of stature estimation indicates that more equations need to be developed to represent the variety of populations around the world, and in particular, Central and South America. The null hypothesis could be rejected because five of the equations were significantly different from known stature. There exists little data that details known stature and long bone lengths for most populations, especially Central or South Americans. More research is necessary on the compilation of data sets for populations around the world. Population variation is significant to stature estimation, as many other authors have suggested, and greater research must be done to account for the many variables that can differentiate populations. This accomplishment would give greater accuracy to stature estimation, and allow a larger number of individuals to be identified.

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Appendix A

Forensic Data Base Hispanic Data

Individual	Forensic Stature	Left Femur (mm)	Right Femur (mm)	Left Tibia (mm)
1	166	459		394
2	175	472	471	378
3	168	467	467	379
4	163			355
5	178	449	445	370
6	188	522	522	442
7	170	455	454	375
8	164	414	407	344
9	167	440	440	371
10	163	418	420	359
11	177			397
12	172	456	454	386
13	178	479	477	398
14	172	452	454	376
15	175	480	478	408
16	170	455	455	
17	170	449	446	367
18	165	425	425	343
19	165	435	433	
20	172	464		393
21	168	439		268
22	160	411		340
23	163	415	418	343
24	175	481		381

Appendix B

Trotter and Gleser's Formulae

White Male Femur Equation

mean (cm)	high	low	Inaccuracy	Bias
172.02	175.96	168.08	6.02	6.02
175.03	178.97	171.09	0.03	0.03
173.87	177.81	169.93	5.87	5.87
169.70	173.64	165.76	8.30	-8.30
186.63	190.57	182.69	1.37	-1.37
171.09	175.03	167.15	1.09	1.09
161.58	165.52	157.64	2.42	-2.42
167.61	171.55	163.67	0.61	0.61
162.51	166.45	158.57	0.49	-0.49
171.32	175.26	167.38	0.68	-0.68
176.66	180.60	172.72	1.34	-1.34
170.39	174.33	166.45	1.61	-1.61
176.89	180.83	172.95	1.89	1.89
171.09	175.03	167.15	1.09	1.09
169.70	173.64	165.76	0.30	-0.30
164.13	168.07	160.19	0.87	-0.87
166.45	170.39	162.51	1.45	1.45
173.18	177.12	169.24	1.18	1.18
167.38	171.32	163.44	0.62	-0.62
160.88	164.82	156.94	0.88	0.88
161.81	165.75	157.87	1.19	-1.19
177.12	181.06	173.18	2.12	2.12
		Average	1.88	0.14

White Male Tibia Equation

mean (cm)	high	low	Inaccuracy	Bias
177.28	181.28	173.28	11.28	11.28
173.41	177.41	169.41	1.59	-1.59
173.65	177.65	169.65	5.65	5.65
167.84	171.84	163.84	4.84	4.84
171.47	175.47	167.47	6.53	-6.53
188.89	192.89	184.89	0.89	0.89
172.68	176.68	168.68	2.68	2.68
165.18	169.18	161.18	1.18	1.18
171.71	175.71	167.71	4.71	4.71
168.81	172.81	164.81	5.81	5.81
178.00	182.00	174.00	1.00	1.00
175.34	179.34	171.34	3.34	3.34
178.25	182.25	174.25	0.25	0.25
172.92	176.92	168.92	0.92	0.92
180.67	184.67	176.67	5.67	5.67
170.74	174.74	166.74	0.74	0.74
164.94	168.94	160.94	0.06	-0.06
177.04	181.04	173.04	5.04	5.04
146.79	150.79	142.79	21.21	-21.21
164.21	168.21	160.21	4.21	4.21
164.94	168.94	160.94	1.94	1.94
174.13	178.13	170.13	0.87	-0.87
		Average	4.11	1.36

White Male Fem + Tib Equation

mean (cm)	high	low	Inaccuracy	Bias
164.32	168.06	160.58	1.68	-1.68
164.36	168.10	160.62	10.64	-10.64
163.83	167.57	160.09	4.17	-4.17
160.66	164.40	156.92	17.34	-17.34
177.06	180.80	173.32	10.94	-10.94
161.92	165.66	158.18	8.08	-8.08
153.65	157.39	149.91	10.35	-10.35
159.63	163.37	155.89	7.37	-7.37
155.66	159.40	151.92	7.34	-7.34
163.15	166.89	159.41	8.85	-8.85
167.24	170.98	163.50	10.76	-10.76
161.64	165.38	157.90	10.36	-10.36
168.37	172.11	164.63	6.63	-6.63
160.36	164.10	156.62	9.64	-9.64
154.94	158.68	151.20	10.06	-10.06
164.85	168.59	161.11	7.15	-7.15
149.20	152.94	145.46	18.80	-18.80
152.88	156.62	149.14	7.12	-7.12
153.68	157.42	149.94	9.32	-9.32
165.80	169.54	162.06	9.20	-9.20
		Average	9.29	-9.29

Mongoloid Male Femur Equation

mean (cm)	high	low	Inaccuracy	Bias
171.26	175.06	167.46	5.26	5.26
174.05	177.85	170.25	0.95	-0.95
172.98	176.78	169.18	4.97	4.97
169.11	172.91	165.31	8.89	-8.89
184.80	188.60	181.00	3.20	-3.20
170.40	174.20	166.60	0.39	0.39
161.58	165.38	157.78	2.42	-2.42
167.17	170.97	163.37	0.17	0.17
162.44	166.24	158.64	0.56	-0.56
170.61	174.41	166.81	1.39	-1.39
175.56	179.36	171.76	2.44	-2.44
169.75	173.55	165.95	2.25	-2.25
175.77	179.57	171.97	0.77	0.77
170.40	174.20	166.60	0.39	0.39
169.11	172.91	165.31	0.89	-0.89
163.95	167.75	160.15	1.06	-1.06
166.10	169.90	162.30	1.09	1.09
172.33	176.13	168.53	0.33	0.33
166.96	170.76	163.16	1.05	-1.05
160.94	164.74	157.14	0.94	0.94
161.80	165.60	158.00	1.21	-1.21
175.99	179.79	172.19	0.98	0.98
		Average	1.89	-0.50

Mongoloid Male Tibia Equation

mean (cm)	high	low	Inaccuracy	Bias
175.62	178.89	172.35	9.62	9.62
171.79	175.06	168.52	3.21	-3.21
172.03	175.30	168.76	4.03	4.03
166.30	169.57	163.03	3.30	3.30
169.88	173.15	166.61	8.12	-8.12
187.09	190.36	183.82	0.91	-0.91
171.08	174.35	167.81	1.07	1.07
163.67	166.94	160.40	0.33	-0.33
170.12	173.39	166.85	3.12	3.12
167.25	170.52	163.98	4.25	4.25
176.33	179.60	173.06	0.67	-0.67
173.70	176.97	170.43	1.70	1.70
176.57	179.84	173.30	1.43	-1.43
171.31	174.58	168.04	0.69	-0.69
178.96	182.23	175.69	3.96	3.96
169.16	172.43	165.89	0.84	-0.84
163.43	166.70	160.16	1.57	-1.57
175.38	178.65	172.11	3.38	3.38
145.50	148.77	142.23	22.50	-22.50
162.71	165.98	159.44	2.71	2.71
163.43	166.70	160.16	0.43	0.43
172.51	175.78	169.24	2.49	-2.49
		Average	3.65	-0.24

Mongoloid Male Fem + Tib Equation

mean (cm)	high	low	Inaccuracy	Bias
165.77	169.01	162.53	0.23	-0.23
165.75	168.99	162.51	9.25	-9.25
165.24	168.48	162.00	2.76	-2.76
162.15	165.39	158.91	15.85	-15.85
178.25	181.49	175.01	9.75	-9.75
163.38	166.62	160.14	6.62	-6.62
155.28	158.52	152.04	8.72	-8.72
161.15	164.39	157.91	5.85	-5.85
157.27	160.51	154.03	5.73	-5.73
164.60	167.84	161.36	7.40	-7.40
168.61	171.85	165.37	9.39	-9.39
163.11	166.35	159.87	8.89	-8.89
169.73	172.97	166.49	5.27	-5.27
161.85	165.09	158.61	8.15	-8.15
156.52	159.76	153.28	8.48	-8.48
166.28	169.52	163.04	5.72	-5.72
150.73	153.97	147.49	17.27	-17.27
154.51	157.75	151.27	5.49	-5.49
155.30	158.54	152.06	7.70	-7.70
167.15	170.39	163.91	7.85	-7.85
		Average	7.82	-7.82

Mexican Male Femur Equation

mean (cm)	high	low	Inaccuracy	Bias
170.67	173.66	167.68	4.67	4.67
173.84	176.83	170.85	1.16	-1.16
172.62	175.61	169.63	4.62	4.62
168.23	171.22	165.24	9.77	-9.77
186.04	189.03	183.05	1.96	-1.96
169.69	172.68	166.70	0.31	-0.31
159.69	162.68	156.70	4.31	-4.31
166.03	169.02	163.04	0.97	-0.97
160.66	163.65	157.67	2.34	-2.34
169.93	172.92	166.94	2.07	-2.07
175.55	178.54	172.56	2.45	-2.45
168.96	171.95	165.97	3.04	-3.04
175.79	178.78	172.80	0.79	0.79
169.69	172.68	166.70	0.31	-0.31
168.23	171.22	165.24	1.77	-1.77
162.37	165.36	159.38	2.63	-2.63
164.81	167.80	161.82	0.19	-0.19
171.89	174.88	168.90	0.11	-0.11
165.79	168.78	162.80	2.21	-2.21
158.95	161.94	155.96	1.05	-1.05
159.93	162.92	156.94	3.07	-3.07
176.03	179.02	173.04	1.03	1.03
		Average	2.31	-1.30

Mexican Male Tibia Equation

mean (cm)	high	Low	Inaccuracy	Bias
173.60	177.33	169.87	7.60	7.60
169.83	173.56	166.10	5.17	-5.17
170.06	173.79	166.33	2.06	2.06
164.40	168.13	160.67	1.40	1.40
167.94	171.67	164.21	10.06	-10.06
184.93	188.66	181.20	3.07	-3.07
169.12	172.85	165.39	0.88	-0.88
161.80	165.53	158.07	2.20	-2.20
168.18	171.91	164.45	1.18	1.18
165.34	169.07	161.61	2.34	2.34
174.31	178.04	170.58	2.69	-2.69
171.72	175.45	167.99	0.28	-0.28
174.55	178.28	170.82	3.45	-3.45
169.36	173.09	165.63	2.64	-2.64
176.91	180.64	173.18	1.91	1.91
167.23	170.96	163.50	2.77	-2.77
161.57	165.30	157.84	3.43	-3.43
173.37	177.10	169.64	1.37	1.37
143.87	147.60	140.14	24.13	-24.13
160.86	164.59	157.13	0.86	0.86
161.57	165.30	157.84	1.43	-1.43
170.54	174.27	166.81	4.46	-4.46
		Average	3.88	-2.18

FORDISC's Formulae

White Male Femur Equation

mean (cm)	high	low	Inaccuracy	Bias
171.83	181.48	162.18	5.83	5.83
175.16	184.82	165.51	0.16	0.16
173.88	183.53	164.23	5.88	5.88
169.26	178.92	159.61	8.74	-8.74
187.99	197.64	178.34	0.01	-0.01
170.80	180.45	161.15	0.80	0.80
160.28	169.94	150.63	3.72	-3.72
166.95	176.61	157.30	0.05	-0.05
161.31	170.96	151.66	1.69	-1.69
171.06	180.71	161.41	0.94	-0.94
176.96	186.61	167.31	1.04	-1.04
170.03	179.69	160.38	1.97	-1.97
177.22	186.87	167.56	2.22	2.22
170.80	180.45	161.15	0.80	0.80
169.26	178.92	159.61	0.74	-0.74
163.11	172.76	153.45	1.89	-1.89
165.67	175.32	156.02	0.67	0.67
173.11	182.76	163.46	1.11	1.11
166.70	176.35	157.05	1.30	-1.30
159.51	169.17	149.86	0.49	-0.49
160.54	170.19	150.89	2.46	-2.46
177.47	187.12	167.82	2.47	2.47
		Average	2.04	-0.23

White Male Tibia Equation

mean (cm)	high	low	Inaccuracy	Bias
177.20	187.36	167.04	11.20	11.20
173.30	183.46	163.14	1.70	-1.70
173.54	183.70	163.38	5.54	5.54
167.69	177.85	157.53	4.69	4.69
171.35	181.51	161.19	6.65	-6.65
188.91	199.07	178.75	0.91	0.91
172.57	182.73	162.41	2.57	2.57
165.01	175.17	154.85	1.01	1.01
171.59	181.75	161.43	4.59	4.59
168.67	178.83	158.51	5.67	5.67
177.93	188.09	167.77	0.93	0.93
175.25	185.41	165.09	3.25	3.25
178.18	188.34	168.02	0.18	0.18
172.81	182.97	162.65	0.81	0.81
180.61	190.77	170.45	5.61	5.61
170.62	180.78	160.46	0.62	0.62
164.77	174.93	154.61	0.23	-0.23
176.96	187.12	166.80	4.96	4.96
146.48	156.64	136.32	21.52	-21.52
164.03	174.19	153.87	4.03	4.03
164.77	174.93	154.61	1.77	1.77
174.03	184.19	163.87	0.97	-0.97
		Average	4.06	1.24

White Male Fem + Tib Equation

mean (cm)	high	low	Inaccuracy	Bias
174.17	183.57	164.78	8.17	8.17
173.76	183.16	164.36	1.24	-1.24
173.21	182.61	163.82	5.21	5.21
169.51	178.91	160.11	8.49	-8.49
189.40	198.80	180.00	1.40	1.40
171.02	180.42	161.62	1.02	1.02
161.14	170.54	151.74	2.86	-2.86
168.41	177.81	159.01	1.41	1.41
163.75	173.15	154.35	0.75	0.75
172.66	182.06	163.27	0.66	0.66
177.47	186.86	168.07	0.53	-0.53
170.74	180.14	161.35	1.26	-1.26
178.97	188.37	169.58	3.97	3.97
169.10	178.50	159.70	0.90	-0.90
162.51	171.91	153.12	2.49	-2.49
174.72	184.12	165.32	2.72	2.72
154.15	163.55	144.75	13.85	-13.85
160.18	169.58	150.78	0.18	0.18
161.14	170.54	151.74	1.86	-1.86
175.41	184.81	166.01	0.41	0.41
		Average	2.97	-0.38

Hispanic Male Femur Equation

mean (cm)	high	low	Inaccuracy	Bias
171.46	177.81	177.81	5.46	5.46
174.30	180.90	180.90	0.70	-0.70
173.21	179.56	179.56	5.21	5.21
169.28	175.63	175.63	8.72	-8.72
185.22	191.83	191.83	2.78	-2.78
170.59	176.94	176.94	0.59	0.59
161.63	167.98	167.98	2.37	-2.37
167.31	173.66	173.66	0.31	0.31
162.50	168.85	168.85	0.50	-0.50
170.81	177.16	177.16	1.19	-1.19
175.83	182.43	182.43	2.17	-2.17
169.93	176.28	176.28	2.07	-2.07
176.05	182.65	182.65	1.05	1.05
170.59	176.94	176.94	0.59	0.59
169.28	175.63	175.63	0.72	-0.72
164.03	170.38	170.38	0.97	-0.97
166.22	172.57	172.57	1.22	1.22
172.55	178.90	178.90	0.55	0.55
167.09	173.44	173.44	0.91	-0.91
160.98	167.33	167.33	0.98	0.98
161.85	168.20	168.20	1.15	-1.15
176.27	182.87	182.87	1.27	1.27
		Average	1.88	-0.32

Hispanic Male Tibia Equation

mean (cm)	high	low	Inaccuracy	Bias
173.83	183.48	164.18	7.83	7.83
171.63	181.29	161.98	3.37	-3.37
171.77	181.42	162.12	3.77	3.77
168.48	178.13	158.83	5.48	5.48
170.54	180.19	160.88	7.46	-7.46
180.41	190.06	170.76	7.59	-7.59
171.22	180.87	161.57	1.22	1.22
166.97	176.62	157.32	2.97	2.97
170.67	180.33	161.02	3.67	3.67
169.03	178.68	159.38	6.03	6.03
174.24	183.89	164.59	2.76	-2.76
172.73	182.38	163.08	0.73	0.73
174.38	184.03	164.72	3.62	-3.62
171.36	181.01	161.71	0.64	-0.64
175.75	185.40	166.10	0.75	0.75
170.12	179.78	160.47	0.12	0.12
166.83	176.48	157.18	1.83	1.83
173.69	183.34	164.04	1.69	1.69
156.55	166.20	146.89	11.45	-11.45
166.42	176.07	156.77	6.42	6.42
166.83	176.48	157.18	3.83	3.83
172.04	181.70	162.39	2.96	-2.96
		Average	3.92	0.30

Hispanic Male Fem + Tibia Equation

mean (cm)	high	low	Inaccuracy	Bias
173.99	181.61	166.37	7.99	7.99
173.71	181.33	166.09	1.29	-1.29
173.34	180.96	165.72	5.34	5.34
170.80	178.42	163.18	7.20	-7.20
184.42	192.04	176.80	3.58	-3.58
171.83	179.45	164.21	1.83	1.83
165.06	172.68	157.44	1.06	1.06
170.05	177.67	162.43	3.05	3.05
166.85	174.47	159.23	3.85	3.85
172.96	180.58	165.34	0.96	0.96
176.25	183.87	168.63	1.75	-1.75
171.64	179.26	164.02	0.36	-0.36
177.28	184.90	169.66	2.28	2.28
170.52	178.14	162.90	0.52	0.52
166.00	173.62	158.38	1.00	1.00
174.37	181.99	166.75	2.37	2.37
160.27	167.89	152.65	7.73	-7.73
164.41	172.03	156.79	4.41	4.41
165.06	172.68	157.44	2.06	2.06
174.84	182.46	167.22	0.16	-0.16
		Average	2.94	0.73

Genoves' Formulae

Mesoamerican Male Femur

mean (cm)	high	low	Inaccuracy	Bias
167.61	171.03	164.20	1.61	1.61
170.55	173.97	167.13	4.45	-4.45
169.42	172.84	166.00	1.42	1.42
165.35	168.77	161.94	12.65	-12.65
181.85	185.27	178.43	6.15	-6.15
166.71	170.13	163.29	3.29	-3.29
157.44	160.86	154.03	6.56	-6.56
163.32	166.74	159.90	3.68	-3.68
158.35	161.76	154.93	4.65	-4.65
166.94	170.35	163.52	5.07	-5.07
172.13	175.55	168.72	5.87	-5.87
166.03	169.45	162.61	5.97	-5.97
172.36	175.78	168.94	2.64	-2.64
166.71	170.13	163.29	3.29	-3.29
165.35	168.77	161.94	4.65	-4.65
159.93	163.35	156.51	5.07	-5.07
162.19	165.61	158.77	2.81	-2.81
168.74	172.16	165.33	3.26	-3.26
163.09	166.51	159.68	4.91	-4.91
156.77	160.18	153.35	3.24	-3.24
157.67	161.09	154.25	5.33	-5.33
172.59	176.00	169.17	2.42	-2.42
		Average	4.50	-4.22

Mesoamerican Male Tibia

mean (cm)	high	low	Inaccuracy	Bias
168.48	171.29	165.66	2.48	2.48
165.34	168.15	162.53	9.66	-9.66
165.54	168.35	162.72	2.46	-2.46
160.83	163.64	158.02	2.17	-2.17
163.77	166.58	160.96	14.23	-14.23
177.88	180.70	175.07	10.12	-10.12
164.75	167.56	161.94	5.25	-5.25
158.68	161.49	155.86	5.32	-5.32
163.97	166.78	161.16	3.03	-3.03
161.62	164.43	158.80	1.38	-1.38
169.06	171.88	166.25	7.94	-7.94
166.91	169.72	164.10	5.09	-5.09
169.26	172.07	166.45	8.74	-8.74
164.95	167.76	162.14	7.05	-7.05
171.22	174.03	168.41	3.78	-3.78
163.18	166.00	160.37	6.82	-6.82
158.48	161.29	155.67	6.52	-6.52
168.28	171.09	165.47	3.72	-3.72
143.78	146.59	140.97	24.22	-24.22
157.89	160.70	155.08	2.11	-2.11
158.48	161.29	155.67	4.52	-4.52
165.93	168.74	163.12	9.07	-9.07
		Average	6.62	-6.40