AGE ESTIMATION OF SUBADULTS FROM A FORENSIC CONTEXT USING THE DENVER LONGITUDINAL STUDY DIAPHYSEAL LONG BONE LENGTH STANDARDS

THESIS

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For my Grandfather, Richard B Kitowski

Who taught me. .

Laugh Often, Love Generously,

and Dream Big!

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CHAPTER I

INTRODUCTION

Medical examiners and coroners offices receive an estimated 4,400 unidentified human bodies in an average year (Hickman and Hughes 2007). Roughly 1,000 of these individuals will remain unidentified after one year and about 600 will eventually undergo final disposition (Hickman and Hughes 2007). Although no comprehensive data on the number of unidentified subadult remains exist at the current time, subadults comprise roughly 40-150 of the forensic anthropological cases analyzed each year (Lewis and Rutty 2003). According to the FBI's National Crime Information Center, in 2008, a total of 598,485 children under the age of 21 were reported missing (Unit 2008). Of these, 24,158 were considered endangered (Unit 2008). In addition, cases of child murder in the United States have risen by 50% in the last 30 years (Lewis and Rutty 2003). Between 2004 and 2006, an average of 726 subadults between the ages of 1 and 14-years-old died by homicide (CDC/NCHS 2009). If these children end up, as recovered unknown subadult remains found in a forensic anthropological context, it is necessary to use any and all identifying characteristics to help identify them.

The major identifying characteristics of any unidentified skeleton are age, sex, ancestry, and stature (Ubelaker 1999; White 2000). This thesis examines the use of diaphyseal long bone length standards for age estimation and its applicability for modern subadults from forensic contexts. When dealing with subadult remains, the study of stature has implications for age estimation because determining sex and ancestry may be especially difficult. In fact, Scheuer and Black state that the “major problem in the skeletal analysis of juvenile remains still to be resolved is the ineffectiveness of most methods of sexing” (2000:15). Estimating sex in subadults is difficult because males and females mature at different times and rates (Lewis 2007; Scheuer and Black 2000). Following maturity, when the bones of males and females become sufficiently differentiated, methods for estimating sex are more accurate and require narrower error ranges (Scheuer and Black 2000; White 2000). Estimating ancestry in subadults is problematic because many of the features used to estimate ancestry occur with development that takes place after puberty (Lewis 2007).

It is essential that accuracy be achieved in subadult age estimation, especially in cases of fragmentary remains when the usual elements for ancestry estimation are missing and the remains have not yet developed any strong sex characteristics. The reliability of age estimation in children is usually high if the majority of the skeleton is intact and the teeth are present or in the process of eruption (Hoffman 1979; Kerley 1976). However, when the skeleton is fragmentary, which is common in subadults because the bones are less durable than those of adults (Kerley 1976), age estimation becomes more problematic. In such cases, a correlation between diaphyseal long bone length and age is commonly utilized (Pfau and Sciulli 1994, Ubelaker 1974, Walker et al. 1997).

The Denver Longitudinal Study (DLS) standards are currently used to estimate subadult age using diaphyseal long bone lengths. The DLS was part of a study on healthy human growth and development conducted by the Child Research Council in Denver, Colorado. The study measured the diaphyseal longbone lengths of living, healthy, middle to upper middle class children descending from mixed European ancestral backgrounds, born in the 1930's and 1940's (McCammon 1970). Currently, the mean and standard deviation from the DLS are commonly used in forensic studies of subadult osteology (Scheuer and Black 2000). However, the data from the DLS study may not be entirely accurate for age estimation of subadults from forensic contexts. With secular, socioeconomic, and ethnic changes in the United States population, it is necessary to determine whether the older DLS reference sample is still accurate for age estimation in a modern forensic sample. This thesis examines whether the children measured for the DLS adequately represent present day forensic populations who may have experienced changes in demographic, economic, and measurement factors and secular change in growth since the mid-twentieth century. In this research, I compared the DLS to the Forensic Anthropology Data Bank (FDB) and the Franklin County Medical Examiner's Office (FCMEO) data.

Purpose of Study

This project was a retrospective study to determine if age could be accurately estimated from diaphyseal long bone (see Figure 1-1) length methods in modern subadults from forensic contexts. This project compared the estimated ages based on the DLS standards to the reported ages of subadults from the United States' Forensic Anthropology Data Bank (FDB) and the Franklin County Medical Examiner's Office (FCMEO) in Ohio. The sample of subadults utilized in this study from the FDB comprised 10 males and 18 females aged between 2 to 12 years, born between 1953 and

1993, and the FCMEO sample consisted of 24 males and 4 females aged 2 to 12 years born between 1978 and 1989. Since the method of subadult age estimation using diaphyseal long bone length was created using early to mid-twentieth century healthy individuals, I predicted that the previous DLS standard calculations would produce inaccurate age estimations when compared to FDB and FCMEO samples. If the DLS diaphyseal long bone length standards provide inaccurate age estimations, then it will be necessary to adjust how to determine subadult age using diaphyseal long bone lengths.

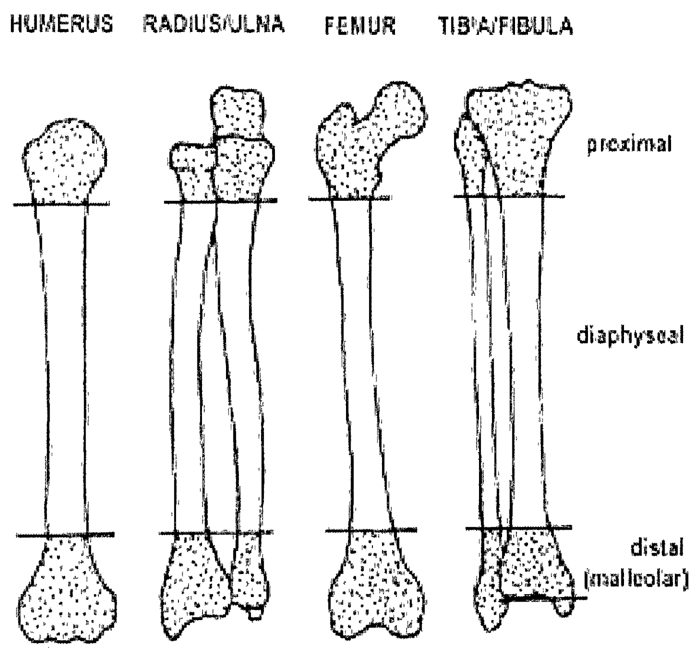


Figure 1-1: Diaphyseal length of the longbones (Haines 1998)

Skeletal Bone Growth and Secular Change

Understanding the healthy growth and development of subadult long bones is important because factors that change typical growth patterns such as secular change in maturation will alter correlations between long bone length and age. Growth can be defined as "an increase in the size of the body as a whole or the size attained by specific parts of the body" (Malina and Bouchard 1991:4). The rate of growth or maturation is independent of age; therefore, a 10-year-old child may have the same diaphyseal long bone length as a 12-year-old child. Differences in maturation, or the process of attaining adult size adds to the variability in the mean subadult long bone lengths of a population at any given age (Malina and Bouchard 1991).

Secular change, which is change in growth and development throughout successive generations of individuals living in the same area, can cause this disjunction between maturation and biological time (Roche 1992). Positive secular change in height occurs largely in developed countries throughout the world (Bogin 1999). Environmental factors such as improved nutrition, control of infectious disease, reduced family size, more widespread health and medical care, increased geographic and social population mobility, decreasing child labor and abuse, and improvements in prenatal care may explain the positive secular trend in developed countries (Bogin 1999; Eveleth and Tanner 1990; Jantz and Jantz 1999; Steckel 1995). In addition, heterosis, the increase in characteristics such as size and growth of a hybrid organism over its parents, may also explain the positive secular trend in developed countries. Heterosis resulting from ethnic and social class migration, intermarriage, and assortive and selective mating without immigration affects a populations height and secular change (Ulijaszek 1998).

In populations with secular height increases, peak height velocity (PHV) and maturation during adolescence occurs earlier than those showing secular decrease or stasis (Beard and Blaser 2002). In the United States and Europe there has been a decrease of roughly three to four months per decade in the age of menarche over the last 100 years (Beard and Blaser 2000). The earlier onset of menarche indicates an increase in the rate of maturation. The early onset of puberty causes subadults to reach their PHV and attain their adult stature earlier causing a disjunction between their height and height standards based on individuals from previous decades. Specifically, there has been a secular increase of 2 to 3 centimeters a decade in height during adolescence (Eveleth and Tanner 1990). The secular increase in subadult stature should be visible in the long bones of healthy modern subadults when their diaphyseal long bone lengths are compared with the DLS standards from the first half of the twentieth century.

Jantz and Jantz (1999) studied secular change in long bone length in individuals from 1800-1970 in the United States. They found that secular change is more pronounced in the lower limb than in the upper limb and that distal bone change is more pronounced than proximal bone change, specifically in the lower limb. This follows the pattern of growth rate found in a longitudinal bone growth study by Smith and Buschang (2004). They found that the larger the bone the faster the growth rate. The proximal bones have a faster growth rate than the distal bones, and the lower limbs have a faster growth rate than upper limbs (Smith and Buschang 2004). Therefore, according to these two studies the faster the growth rate of the long bone the more pronounced the secular change in length. If secular change causes a disjunction between estimated age and actual age in modern subadults when using the DLS standards it should be most noticeable in the femur which has the highest growth rate and most pronounced secular change.

Tanner suggests skeletal maturity or bone age as a more applicable measurement through the whole growth period, because it incorporates differences in maturation and therefore secular change (Tanner 1978). Skeletal maturity is a measure of how far the bones have progressed towards maturity in terms of location and shape. The main method for establishing skeletal maturity is an analysis of the onset and process of ossification in the epiphyses (Roche 1992). However, this is not useful in subadults before the onset of epiphyseal ossification.

Skeletal Bone Growth and Economics

Socioeconomic status influences growth and final adult height by affecting an individual's environment and access to resources (Bogin 1999; Eveleth and Tanner 1990; Steckel 1995). Schell (1997) discusses two main feedback relationships between growth and socioeconomic status. For those with higher socioeconomic status, better environmental conditions lead to increased height, taller individuals tend to rise in socioeconomic status, and higher socioeconomic status leads to better environmental conditions (Schell 1997). Likewise, worse environmental conditions lead to smaller size, smaller individuals tend to fall in socioeconomic status, and lower socioeconomic status leads to worse environmental conditions (Schell 1997) . Socioeconomic status affects human height by influencing interdependent environmental factors such as diet quality, work load, and access to healthcare (Eveleth and Tanner 1990; Steckel 1995). These factors all relate to nutritional uptake, which is important for growth. Subadults need a quality diet to receive the proper nutrition for growth, and they need access to healthcare to combat infections, which inhibit nutrient uptake by the body. In order to receive these things the subadult's parents need to also be receiving proper nutrition so they are healthy enough to work and gain income (Cole 2000; Steckel 1995). It is more difficult for subadults from lower socioeconomic statuses to maintain a quality diet because healthier foods are often more expensive than the less nutritious options and they are more likely to experience repeated infections (Tanner 1962). Differences in socioeconomic conditions within America, adds to the variability in subadult height at any given age. This may be an issue for age estimation when subadult long bone lengths for individuals from lower socioeconomic conditions are compared with the upper-to-upper middle class subadult standards.

Conclusion

The DLS standards may inaccurately estimate ages of modern subadults from forensic contexts, based on the differences between modern subadults from forensic contexts and the individuals used to create the DLS standards. Over the last 100 years subadults in the United States have experienced secular increases in height and an earlier age for maturation and peak height velocity. Furthermore, individuals from forensic contexts will likely be of mixed socioeconomic status. A population with mixed socioeconomic statuses may not be comparable to the upper-to-upper middle class population used for the DLS standards. Previous studies conducted on the correlation between diaphyseal long bone lengths and age have failed to address these issues because of the lack of appropriate radiographic or skeletal collections. The following chapter explores the contributions of these studies to the use of diaphyseal long bone lengths in age estimation.

CHAPTER II

LITERATURE REVIEW

Some investigators use variability in long bone length due to secular change, environment, and socioeconomic status to question the use of diaphyseal long bone length standards for age estimation (Hoffman 1979). Hoffman (1979) compared female subadult variability in diaphyseal radius and femur length from the Denver Longitudinal Study (Maresh 1943; 1955) to tooth eruption times as published by Robinow (1947), Hurme (1948), and Krogman (1972) to determine if there was more variability diaphyseal long bone length standards for age estimation than in tooth eruption standards for age estimation. He plotted the female diaphyseal length mean and the mean +/- 1.96 standard deviations against chronological age and compared it to the mean eruption time and variance for each tooth, which were plotted on the same graph. He found that the range of variability for diaphyseal lengths is either about the same or about less than the variability for tooth eruption ages (Hoffman 1979). In fact, the femur was less variable than tooth eruption times at all ages (Hoffman 1979). Therefore, variability in diaphyseal long bone lengths is not any more significant than those of other more popular aging methods and should not be discontinued. However, it is still important that forensic anthropologists reduce variability as much as possible by providing appropriate long bone length standards.

Research into growth and stature is hampered by laws restricting access to medical radiographs of living children and health risks associated with taking repetitive radiographs of living children (Lewis and Rutty 2003; Pfau and Scuilli 1994). Only three longitudinal studies with comprehensive data for long bone lengths have been used to create long bone length standards, the Denver Longitudinal Study or DLS (McCammon 1970), the Longitudinal Studies of Child Health and Development of the Harvard School of Public Health or LSCHD (Anderson, et al. 1964; Stuart, et al. 1959), and the Fels Longitudinal Study (Gindhart 1973; Roche 1992).

The first complete set of growth standards for the six major long bones were those of the Child Research Council at Denver and were published by Maresh (1943; 1955; 1970), McCammon (1970), and Scheuer and Black (2000). The DLS is the primary source for estimating age in subadults using diaphyseal long bone length standards. This longitudinal study utilized roentgenographs on living individuals to measure the length of the long bones at each given age. This thesis analyzes the data published by McCammon (1970), and Scheuer and Black (2000). In order to avoid repetition, a more in-depth discussion on the Denver Longitudinal Study (DLS) is in the Materials section of this thesis.

Standards on the entire length of the normal femur and tibia for subadults, ages birth to 18, were created from the comprehensive LSCHD of the Harvard School of Public Health and published by Anderson, et al. (1964). The sample used by Anderson, et al. (1964) was derived from regularly repeated roentgenograms of the lower extremities in sixty-seven boys and sixty-seven girls. Measurements were made of the entire bone, including the proximal and distal epiphyses. The femur was measured from the proximal articulating surface of the capital epiphysis to the most distal point on the lateral condyle and the tibia was measured from the mid-point of a line drawn across the proximal condyles to the mid-point of the distal articulating surface (Anderson, et al. 1964). Since these standards include the epiphyses, they are not applicable for use in cases where the epiphyses are absent. This thesis studies only diaphyseal long bone length standards and does not include the epiphyses. However if diaphyseal standards are inapplicable to age estimation of modern subadults from forensic contexts, then it will also be necessary for further research to investigate whether long bone length standards that include the epiphyses, from the first half of the twentieth century, are also inaccurate in age estimation.

The Fels Longitudinal Study includes data for the six major long bones, however access to these standards is restricted. The only reported standards based on the Fels Longitudinal Study were published by Gindhart in 1973. Gindhart (1973) published long bone growth standards for the tibia and radius for individuals 1 to 18 years of age. The sample was made up of individuals enrolled by 1967 in the longitudinal program of the Fels Research Institute for the Study of Human Development (Gindhart 1973). The subjects in the study were white, middle class subadults of northwestern European descent with no mental or major physical abnormalities (Gindhart 1973). Radiographs were taken at the year and half-year mark from ages 1 to 12, and then yearly from 12-18 (Gindhart 1973). Measurements were of the maximum calcified length of the diaphyses of each bone along its longitudinal axis. The actual numbers of individuals fluctuated throughout the years of the study and began to decrease, as children grew older. The method and samples of the Fels Longitudinal Study and the DLS are very similar which allows for comparison of the two sets of standards. Gindhart (1973) compared the Fels and DLS means for length for ages six months to 12 years. After 12 years of age, the DLS included epiphyses so the results were not comparable. She found that the Fels male and female tibia were larger by 6 to 8 percent at all ages. Gindhart (1973) accounts for the difference by citing the larger Fels sample numbers and the inclusion of radiographic correction methods in the Fels longitudinal data. However, it may be possible that the difference is a result of secular change between the first half of the twentieth century and the beginning of the second half of the twentieth century. This suggests that modern upper-to-upper middle class individuals of northern European descent have undergone positive secular change and therefore the DLS may not accurately estimate their ages.

One of the most limiting factors in the use of diaphyseal long bone lengths for age estimation is the lack of modern non-adult skeletal collections. Large skeletal collections of known infants and children are limited because parents rarely choose to donate their children's bodies to medical science (Lewis and Rutty 2003). Currently, the only study of a current forensic subadult population for creating age estimation standards using diaphyseal long bone lengths is Pfau and Scuilli's (1994) radiographic study of subadults, between 0 and 20 years of age, from the Franklin County Medical Examiner's Office in Ohio. Pfau and Scuilli (1994) used 183 subadult cadavers to create a radiographic method that assesses dental development, long bone growth, and epiphyseal fusion in order to provide accurate and precise information on the covariance of age indicators. When using all three methods of age estimation on 15 randomly chosen individuals they had a correlation between the actual ages of the individuals and the ages estimated from the data of .0.982, t = 15.52, P < 0.001 (Pfau and Scuilli 1994). Their study does not look into the correlation between the actual ages of the individuals and the ages estimated specifically by long bone growth. However, they do include correlations between the actual age of the individuals and the DLS standards for the radius and tibia: .989 and .970 respectively, each with P <0.001 (Pfau and Scuilli 1994). They found a high correlation between the actual ages of the individuals and the ages estimated by the DLS indicating that the DLS standards are accurate for age estimation on modern subadult populations. This suggests that issues of poor nutrition, poor health, and lower socioeconomic status in subadults from forensic contexts may counteract positive secular change in these populations. This would account for the DLS standards accuracy in age estimation despite the positive secular change suggested by Gindhart's study of the Fels Longitudinal Study data.

The lack of large collections of subadult remains or long bone radiographs, has limited research on the correlation between diaphyseal long bone lengths and age. Of the three longitudinal studies that have amassed data on diaphyseal long bone lengths, only the DLS includes published standards on all six of the major long bones. Two of these studies, the DLS and the LSCHD, were based on data collected in the first half of the twentieth century, which may not be applicable for modern populations. Furthermore, the tibia and femur standards based on the LSCHD include the epiphyses and are not applicable for use in subadult remains where the epiphyses are absent. The Fel's Longitudinal Study standards for the tibia and radius are based on a more recent population from the second half of the twentieth century. These standards when compared to the DLS suggest positive secular change in height for upper-to-upper middle class children from northern European descent. The Fels Longitudinal Study standards are only applicable if the tibia or the radius is present, which leaves only the DLS standards for use in diaphyseal long bone length age estimation of the other long bones. This means that the DLS, which may not be accurate on modern populations because of secular change, is the best available source for age estimation using diaphyseal long bone length standards. The radiographic method created by Pfau and Scuilli for use on forensic cases indicates that issues of health, nutrition, and socioeconomic status may counteract the positive secular change in subadults from forensic contexts. The DLS may still be accurate for age estimation in modern subadults from forensic contexts. This thesis will compare two different forensic samples, a morgue sample and a forensic data bank sample, to the DLS in order to determine whether the standards are applicable for age estimation in modern subadults from forensic contexts.

CHAPTER III

MATERIALS AND METHODS

The data for this study were obtained from three sources, the Denver Longitudinal Study or DLS (McCammon 1970), Franklin County Medical Examiner's Office or FCMEO (Pfau and Scuilli 1994), and the Forensic Anthropology Data Bank or FDB (Jantz and Moore-Jansen 1998). The only identifying data available in these datasets were: year of birth, year of death, age, diaphyseal longbone lengths, ancestry, and sex. The variables age, sex, and maximum length of the long bones are used in subadult age identification using diaphyseal long bone lengths, and were obtained from these sources.

Materials

The longitudinal data from the DLS were collected between October 1, 1927 and January 1, 1967 in the Denver area by the Child Research Council in a longitudinal study of healthy growth and development. The data from the longitudinal study were published in 1970 (McCammon 1970). The purpose was to observe the growth and development of an individual over time in order to identify the developmental events that may have significance on determining their future developmental course (McCammon 1970). Measurements were taken from the middle and upper middle socioeconomic groups because they were considered more stable within a community.

If the family suffered economic decline or the living situation changed to a single parent environment, the child was dropped from the study (McCammon 1970). All of the subjects had adequate nutrition and received private medical care. Firstborn children were enrolled in the study in preference to later-born children to limit the genetic pool from which the subjects were drawn. The parents' nationality was of mixed European ancestry, but primarily from northern European extraction. The majority of subjects were at least second-generation residents of the United States and in the late years of the study, participation was limited to only second-generation children.

The roentgenographic study of growth in the length of six major long bones began in 1935. The studies included the length of the long bones of the left arm and leg. Early films were eliminated from the study as the radiographic technique was standardized. When calculated from dry bone specimens, there is a magnification of 1 to 1.5 percent with the bone in contact with the cassette and 2 to 3 percent with the bone in a simulated body position with respect to the cassette surface (McCammon 1970).

Starting at age 1, the participants' roentgenograms were examined at the birthday and half-year examinations until long bone growth was judged to be completed. All measurements were made and checked by Maresh until 1957 (McCammon 1970). After 1957, Hansman or Maresh took and checked each measurement (McCammon 1970). If the measurements corresponded to within .05 cm, the measurement was retained. If there was a .1 cm difference in the measurements, additional measurements were made until the two values agreed. From 2 years through 12 years, the length was measured parallel to the long axis of the bone from the most proximal edge to the most distal edge of the diaphyses.

The data were reported as tables containing the sample number for each age interval, mean, standard deviation, 10th, 50th and 90th percentile values for both males and females. For the purposes of this study, the reported the mean was used for male and female children aged 2-12 years. Of the six major longbones measured for the DLS, the data from the humerus, radius, ulna, femur and tibia were used. The fibula was not included in this study because the comparison data from the FDB and the FCMEO study did not include measurements of the fibula.

The data from the FCMEO were used in this study with the permission of Dr. Paul W. Scuilli. The FCMEO data were collected on individuals who had died between 1 July 1990 and 30 June 1991. The FCMEO sample in Ohio is a morgue sample that consists of children who experienced death by homicide, suicide, accidental and natural causes (Spradley 2002). The study collected data on 186 deceased individuals between birth and 20 years. The subject's left radius and tibia were radiographed using 14 x 17 inch x-ray film and there was a magnification of 1 percent with the bone in contact with the cassette. A radiopaque marker was included as a reference point to ensure accurate measurements. The diaphyseal lengths were determined by measuring the maximum calcified lengths on the radiographs to the nearest .1 millimeters. Richard O. Pfau took the measurements and all evaluations were made twice; the second evaluation 30 days after the first. The first measurement was used for analysis, as both measurements did not differ statistically. The FCMEO data obtained for this thesis consisted of male and female children aged 2-12 years. The total sample was comprised of 28 individuals: 24 males and 4 females (see Table 3-1).

The FDB was created in 1986 and contains: cranial and postcranial metrics, suture closure information, various aging criteria scores, non-metric cranial information, perimortem trauma, congenital traits, and dental observations on adults and subadults. Out of the over 2100 cases, 1600 have been positively identified. For the purposes of my study, the data from the FDB accessed in December of 2008 contained 28 positively or tentatively identified subadults: 18 female and 10 male individuals born between 1957 and 1993 (see Table 3-1). Tentatively identified subadults were subadults identified based on soft tissue, and for the purposes of this study, I considered them positively identified. Forensic anthropologists from across the country conducted the sex estimation, ancestry estimation, and diaphyseal measurements.

Although most cases in the FDB contain little demographic information, the information available indicates that a majority of the FDB subadult cases result from homicide (Spradley 2002). A study using the 1990 U.S. Deprivation Index, which divides regions into five socioeconomic quantiles, found that between 1998-2000, children aged 1through 14 in the most deprived socioeconomic quantile had a 159% higher homicide rate than did children in the least deprived socioeconomic quantile (Singh and Kogan 2007). This suggests that the majority of subadult cases in the FDB may be individuals from lower socioeconomic status. If this is the case, these children would not have received the same nutrition and healthcare as an upper-to-upper middle class child, resulting in stunted growth. Furthermore, although there is no direct evidence for abuse in the FDB data, several individuals are noted as "growth retarded" and additional individuals have signs of healing long bone fractures (Spradley 2002). These traits are consistent with child abuse cases.

The DLS and FCMEO measured the left long bones so measurements on the left long bones from the FDB were used in preference over right long bones. However, because the subjects came from actual forensic cases, the left bones were not always available. In such cases, the right bone was used when the left was unavailable. When both the left and right bones were unavailable, the subject was left out of the analysis.

TABLE 3-1: Total Sample Composition

FORENSIC ANTHROPOLOGY DATA BANK

Sex	Number of Individuals	Number of Humeri	Number of Radii	Number of Ulnae	Number of Femurs	Number of Tibiae
Males	10	8	6	6	9	8
Females	18	17	15	16	16	13

FRANKLIN COUNTY MEDICAL EXAMINER'S OFFICE

Sex	Number of Individuals	Number of Radii	Number of Tibiae
Males	24	24	23
Females	4	4	4

Methods

Descriptive statistics were used to compare the FDB and FCMEO data to the DLS mean and standard deviations. The differences between the FDB and FCMEO samples and the DLS were visually depicted using overlay scatterplot graphs in SPSS 17.0 for the Apple Macintosh. The FCMEO data were analyzed separately from the FDB data. Only FCMEO tibia and radius data were available for comparison to the DLS data. The data were stratified by the factors listed in Table 3-2.

TABLE 3-2: Variable Factors

Subadult Variables	Variables
Sex	1 = Male 2 = Female
Age	< .75 remained the given year > .75 rounded to the next greater year

Since measurements were taken in centimeters for the DLS, all data from the FDB and FCMEO were converted from millimeters to centimeters. The DLS measurements were rounded to the nearest single decimal point in order to coincide with the FDB measurements, which were only taken to the first decimal place.

The data from the FDB and FCMEO were analyzed by individual long bone; to determine which DLS age the mean diaphyseal length was closest to. In certain cases, the diaphyseal measurement exceeded the longest diaphyseal standard deviation in length in the DLS, in these cases the estimation was stated as 'could not be determined'. Paired student's t-tests were used to determine statistical significance on the difference between the DLS estimated age and the reported age for each long bone in the FDB and FCMEO samples. For samples showing significant differences between the estimated and reported age, the data was reviewed to determine whether the trend was toward overestimation or underestimation.

CHAPTER IV

RESULTS

Paired t-tests were used to compare the difference between reported age and age estimated using the DLS standards (see Table 4-1). The data were analyzed separately by sample source and long bone. The data fulfill the assumption of independence of variance and random sampling and were checked for normalcy using the Shapiro-Wilk test for normality. All samples were normal except for the FCMEO estimated ages of the tibia and the FCMEO reported ages, which had $p < .05$ (see Table 4-2). The null hypothesis for the paired t-test states that there is no difference between the mean reported ages and the mean estimated ages of each sample.

TABLE 4-1: Paired T-tests

	Pair Differences							
Pairs	Mean	Std Deviation	Std Error Man	95% CI of the Difference		t	df	Sig (2-tailed)
FDB Reported Age – Humerus Estimated Age	261	864	180	- 113	635	1 447	22	162
FDB Reported Age – Radius Estimated Age	050	945	211	- 392	492	237	19	815
FDB Reported Age – Ulna Estimated Age	- 273	935	199	- 687	142	-1 368	21	186
FDB Reported Age – Femur Estimated Age	042	1 301	266	- 508	591	157	23	.877
FDB Reported Age – Tibia Estimated Age	250	851	190	- 148	648	1 314	19	204
FCMEO Reported Age – Radius Estimated Age	- 400	913	183	- 777	- 023	-2 191	24	038
FCMEO Reported Age – Tibia Estimated Age	- 538	905	177	- 904	- 173	-3 035	25	006

TABLE 4-2: Shapiro-Wilk Test for Normality

	Statistic	df	Sig.
FDB			
Humerus Estimated Age	.943	23	.210
Radius Estimated Age	.938	20	.219
Ulna Estimated Age	.924	22	.092
Femur Estimated Age	.934	24	.121
Tibia Estimated Age	.961	20	.555
Reported Age	.930	28	.061
FCMEO			
Radius Estimated Age	.939	25	.138
Tibia Estimated Age	.906	26	.021
Reported Age	.903	28	.014

FDB Age Estimations

The significance between the reported age and the estimated age for the FDB were all $p > .05$ (see Table 4-1). For the five long bones, humerus, radius, ulna, femur and tibia, in the FDB, the null hypothesis of no difference is accepted.

Individual 662 was excluded from the FDB t-tests because their age estimation based on DLS diaphyseal long bone lengths could not be determined (see Table 4-3). Individual 1509's humerus and radius were also excluded from the FDB t-tests for the same reason. These individuals' diaphyseal lengths were longer than the standard deviation for twelve year olds in the DLS (See Appendix A: Tables 5-2, 5-4, 5-7, and 5-9). Individual 182's humerus was excluded from the FDB t-tests because her diaphyseal humerus length fell below one year of age (see Table 4-4).

FCMEO Age Estimations

The FCMEO tibia and radius estimated ages were reported at $t = -2.191$, $df = 24$, $p < .05$ and $t = -3.035$, $df = 24$, $p < .05$, respectively (see Table 4-1). The null hypothesis of no difference for the FCMEO tibia and radius is rejected: the FCMEO age estimations were significantly different than the FCMEO reported ages. The majority of inaccurate age estimations in the radius were due to overestimation of the individual's age (see Tables 4-5 and 4-6).

From the FCMEO sample, the tibia and radius for Individual 23 and the radius for Individual 26 were not included in the t-test because their age estimation based on DLS diaphyseal long bone lengths could not be determined (see Table 4-5). Individual 23's and 26's diaphyseal lengths were longer than the highest standard deviation for 12 year olds in the DLS (See Appendix A: Tables 5-11 and 5-13). Individual 25 had no tibia and was not included in the t-test for the tibia. Individual 8's radius was also not included in the t-test because their age was estimated below one year of age (See table 4-6).

TABLE 4-3: Male FDB Reported Age vs. DLS Estimated Age by Long Bone

Individual	FDB Reported Age	Estimated Ages using DLS Standards				
		Humerus	Radius	Ulna	Femur	Tibia
608	2	2				
1233	5	4	4	4	5	4
1397	5	5	5	6	5	5
1510	5	5	5	6	5	5
605	6	6			7	6
595	7	7	6	6	6	6
604	8				8	
1139	11	11	12	12	12	11
662	12				CBD*	CBD*
1519	12	11	10	12	12	12

*Could not be determined: Individual's maximum diaphyseal long bone length was over the maximum standard deviation for twelve year olds in the DLS

TABLE 4-4: Female FDB Reported Age vs. Estimated Age by Long Bone

Individual	FDB Reported Age	Estimated Ages using DLS Standards				
		Humerus	Radius	Ulna	Femur	Tibia
219	2	2	2	2	2	2
618	2	3	4	4	4	2
615	3	3	3	3	3	3
1185	3	3	3	3	3	3
610	4	5	5	5	5	6
1585	4	4	4	4		
609	5	5	6	6	5	6
775	5				6	
182	6	< 1	6	6	5	6
1463	7	7	7	7	7	7
1606	7	8	8	8		
817	8	7	7	7	7	7
607	9	8		11	10	8
616	10	10	10	9	11	9
779	10	9		10	10	9
606	11	10	10		8	9
1509	11	CBD*	CBD*	12	12	
617	12	9	11	11	8	

*Could not be determined: Individual's maximum diaphyseal long bone length was over the maximum standard deviation for twelve year olds in the DLS

TABLE 4-5: Male FCMEO Reported Age vs. DLS Estimated Age by Long Bone

Individual	FCMEO Reported Age	Estimated Ages using DLS Standards	
		Radius	Tibia
4	2	2	3
7	2	3	3
22	2	2	3
9	3	4	4
11	3	4	4
13	3	4	4
17	3	5	4
19	3	2	3
16	4	4	3
6	5	5	5
12	5	6	6
15	5	5	5
27	5	5	5
2	7	8	7
20	7	8	8
1	8	8	8
8	8	10	10
21	8	7	7
3	10	10	12
5	10	10	12
10	10	11	10
23	10	CBD*	CBD*
25	11	10	
26	12	CBD*	12

*Could not be determined: Individual's maximum diaphyseal long bone length was over the maximum standard deviation for twelve year olds in the DLS

TABLE 4-6: Female FCMEO Reported Age vs. DLS Estimated Age by Long Bone

Individual	FCMEO Reported Age	Estimated Ages using DLS Standards	
		Radius	Tibia
18	2	< 1	1
24	6	6	6
14	10	12	12
28	10	9	10

CHAPTER V

DISCUSSION

The purpose of this research was to determine whether the DLS diaphyseal longbone length standards could be used for age estimation in modern subadults from a forensic setting. Results of this research show that the DLS is not an accurate source for age estimation of modern subadults in a morgue setting. Based on this research the FCMEO age estimations using the DLS standards were significantly different than the individuals' reported ages.

The FCMEO individuals' ages generally were overestimated by at least a year. The DLS's tendency to predict an older age for the individuals in the FCMEO may be due to the positive secular change that has occurred in the last half century. Nine of the 26 individual's ages in the FCMEO were overestimated by 1 year when using the radius and two individual's ages were overestimated by 2 years. Only three individual's ages were underestimated and they were each underestimated by 1 year. The majority of inaccurate age estimations in the tibia were due to overestimation of the individual's age (see Table 4-5 and 4-6). Nine of the 26 individual's ages in the FCMEO were overestimated by 1 year and three individual's ages were overestimated by 2 years. Only two individual's ages were underestimated and they were each underestimated by 1 year.

The similarities in age inaccuracies between the tibia and the radius indicate that the faster growth rate in the lower limbs does not result in more inaccurate age estimations when compared with the upper limbs. It should be noted that the sample sizes were small and only included the radius and tibia. To further explore the relationship between long bone growth rate and age estimation future research should compare age estimations in the femur and humerus from a larger sample, since the femur has the highest growth rate of the long bones.

Pfau and Scuilli found high levels of correlation between the DLS estimated ages and the ages of the FCMEO individuals when including all 183 subadult individuals between the ages of birth and 20. This thesis found significant differences between the DLS estimated ages and the ages of the FCMEO individuals when the sample was reduced to the 28 individual's between the ages of 2 and 12. This may suggest that the individuals are not showing an overall change in height at all ages, but merely a change in the patterns of maturation. In other words, these individuals may be reaching their PHV earlier, creating longer diaphyseal lengths at earlier ages, but their resulting adult diaphyseal lengths may not have increased enough to alter age estimation. It would be necessary to compare the diaphyseal long bone lengths for FCMEO individuals ages 12 to 20 to determine if this is the case.

The FDB age estimations using the DLS standards did not differ significantly from the individual's reported ages. It is likely that these children did not share the same positive nutrition and healthcare experience as children in the upper-to-upper middle classes sampled by the DLS study. Shorter stature resulting from poor nutrition and possible cases of abuse would negate positive secular change in these individuals and may explain why the DLS is still accurately estimating their ages.

It is interesting to note that while the sample size from the FDB and the sample size from the FCMEO were the same (28 individuals) the breakdown of male and females is very different. The FDB sample had more females (18) than males (10) and the FCMEO had significantly more males (24) than females (4). The larger male sample may be partially why the FCMEO showed significant difference, since males tend to exhibit secular change more than females.

CHAPTER VI

CONCLUSION

Accurate estimation of a subadult's age is of increasing importance in forensic, judiciary, and clinical settings (Scheuer and Black 2000). The preliminary study presented here suggests that the DLS diaphyseal longbone length data, which has previously been used to provide age estimations in forensic settings is not accurate in estimating age in modern subadult morgue cases, but is still applicable for subadult forensic anthropology cases like those reported to the FDB. The FDB did not show significant differences between the DLS estimated and reported ages. This may be due to a larger portion of the children being from lower socioeconomic classes where the effects of poor nutrition would mask secular increases in height. Estimating the age of modern children such as those found in a morgue setting is likely to result in over aging (see Tables 4-3 and 4-4). The FCMEO sample showed significant differences between the estimated age using the DLS standards and the reported age. The DLS tended to overestimate the age of the children based on their diaphyseal tibia and radius lengths. As morgue cases tend to include subadults from upper-to-upper middle as well as lower socioeconomic classes, many of these children may clearly show secular increases in height. These preliminary results indicate that there could be significant age estimation errors if the DLS is used in cases where the child was healthy and received adequate nutrition throughout their growth.

For the purposes of this study, the exact socioeconomic status and manner of death for the children were not included. Further research using data that includes socioeconomic status and manner of death are necessary to determine the extent of significance of these variables have on age estimation. For example, a population within the FCMEO subadults exists for accidental deaths (Spradley 2002). It would be interesting to see whether age estimation of children who died from accidental deaths are as accurate when compared to children who died of homicide, suicide or natural deaths. If a subadult's age is inaccurately estimated, they can be excluded from a search of missing persons, or in the case of living individuals, they may be tried under inappropriate judiciary procedures. Further research may provide more details on the extent of error when using the DLS reference data.

Future research should focus on increasing the sample size of the comparative population to support the results obtained in this study. In light of these preliminary results, it is suggested that new databases of subadult diaphyseal longbone lengths from forensic context be created for more accurate age estimation.

In addition, future research should look into studies of secular change in subadults, as there currently are few studies confirming secular trends in American subadults. If secular increase is occurring it will be helpful to know the rate of increase and whether it has affected the growth rate patterns typically associated with long bone growth. The lack of documented subadult collections is one of the most limiting factors for future research. The creation of large collections with more complete demographic information such as socioeconomic status, ethnicity, and geographic location is necessary to improve methods of age estimation using diaphyseal long bone lengths. At the time of this thesis, Mercyhurst College was awarded funding to create a digital database of modern subadults radiographic and demographic data collected from geographically diverse medical examiner and coroner offices in the United States (Stull et al. 2009). Once the database is available to researches, analyses into the differences between year of birth, sex, ethnicity, manner of death, and long bone length might yield more detailed information about the changing demographic profile in forensic anthropology subadult cases and the possible implications for age estimation of children.

APPENDIX

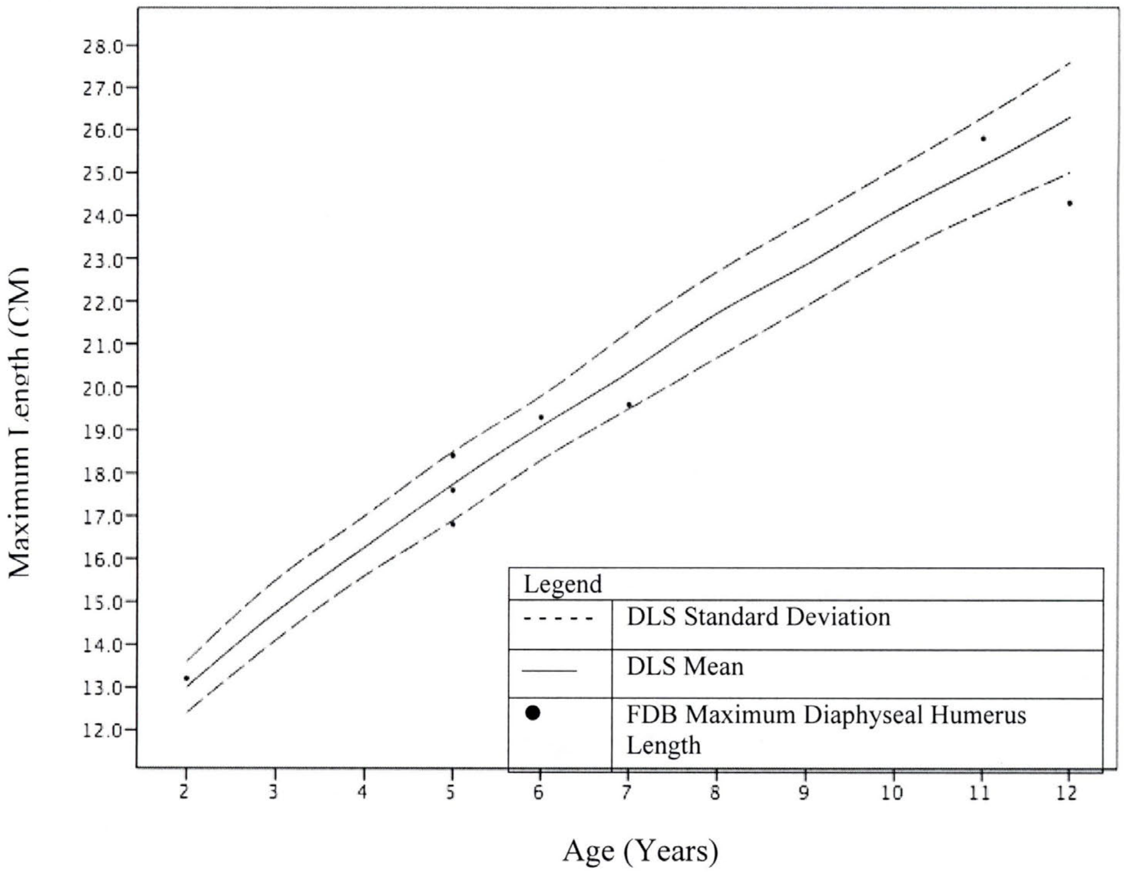
GRAPHS AND DATA

The following results are arranged in anatomically descending order starting with the humerus and ending with the tibia. The Forensic Anthropology Data Bank (FDB) sample is reported first and then the Franklin County Medical Examiner's Office (FCMEO) data. The results for each longbone are separated by the sex of the sample with results for males first and then the results for females. Each section begins with a table listing the maximum diaphyseal length for each individual from the sample and the mean and standard deviation for individuals of the same age from the DLS. The tables are followed by a graph visually depicting where the FDB data fell in relation to the longbone length mean and standard deviation estimated by the Denver Longitudinal Study (DLS) for individuals, ages 2 to 12.

Forensic Anthropology Data Bank

FDB Male Humerus Lengths: Individual's maximum diaphyseal humerus length compared to the DLS maximum diaphyseal humerus length mean and standard deviation

Individual	Age (Years)	FDB Maximum Diaphyseal Humerus Length (cm)	DLS Mean (cm)	DLS Standard Deviation (cm)
608	2	13.2	13.0	.6
1233	5	16.8	17.7	.8
1397	5	17.6		
1510	5	18.4		
605	6	19.3	19.2	.8
595	7	19.6	20.4	.9
1139	11	25.8	25.2	1.1
1519	12	24.3	26.3	1.3

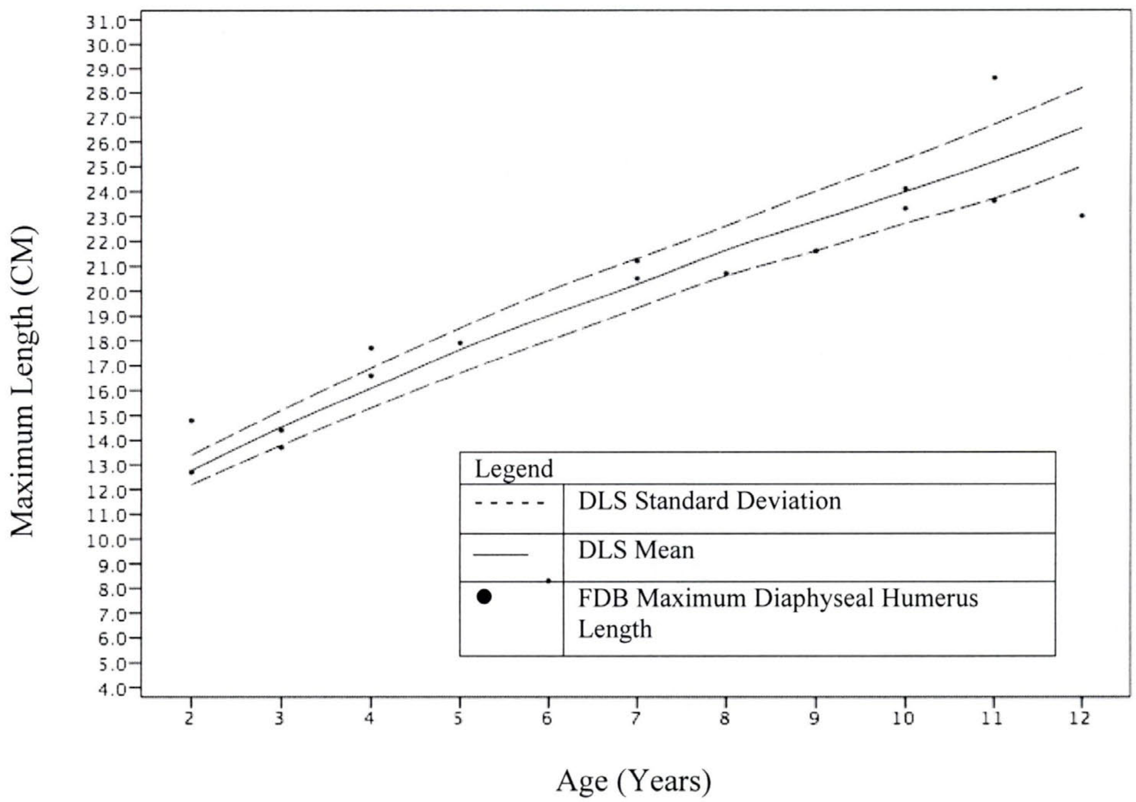


FDB Male Humerus Lengths: Comparison of the FDB male diaphyseal humerus lengths to the male diaphyseal humerus lengths estimated by the DLS

FDB Female Humerus Lengths: Individual's maximum diaphyseal humerus length compared to the DLS maximum diaphyseal humerus length mean and standard deviation

Individual	Age (Years)	FDB Maximum Diaphyseal Humerus Length (cm)	DLS Mean (cm)	DLS Standard Deviation (cm)
219	2	12.7	12.8	.6
618	2	14.8		
615	3	13.7	14.5	.7
1185	3	14.4		
610	4	17.7	16.1	.8
1585	4	16.6		
609	5	17.9	17.6	.9
182*	6	8.3	19.0	1
1463	7	20.5	20.3	1
1606	7	21.2		
817	8	20.7	21.6	1
607	9	21.6	22.8	1.2
616	10	24.1	24.0	1.3
779	10	23.3		
606	11	23.6	25.2	1.5
1509	11	28.6**		
617	12	23.0	26.6	1.6

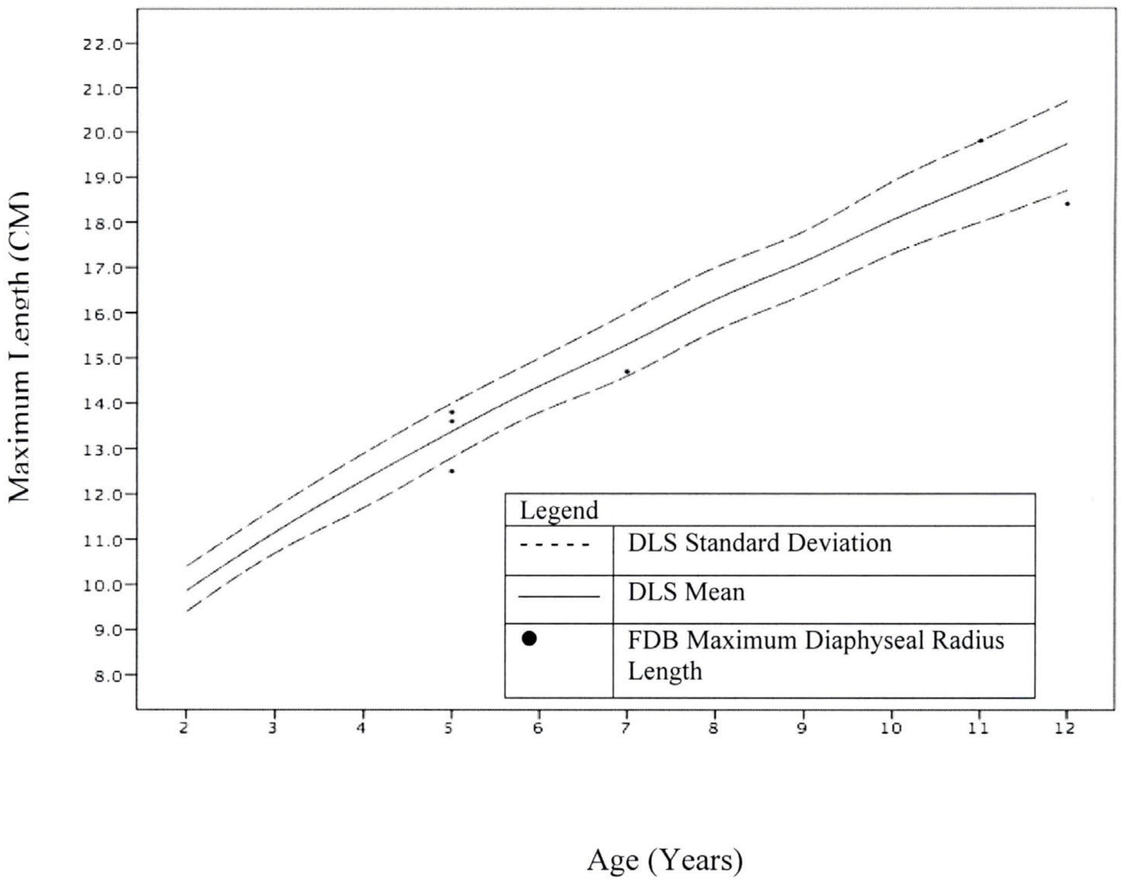
* Individual 182's maximum diaphyseal humerus length is shorter than 10.9 cm standard deviation lower limit for 1-year-old females in the DLS. Both the right and left humeri measured to 8.3 cm according to the FDB, however the individual's other long bones fell within the 6-year-old age classification indicating either a data entry error or a pathological disturbance that caused the short diaphyseal humerus length.
* *Individual 1509's maximum diaphyseal humerus length is greater than the 28.2 cm standard deviation upper limit for 12-year-old females in the DLS. This may be due to the inclusion of epiphyses during measurement.



FDB Female Humerus Lengths: Comparison of the FDB female diaphyseal humerus lengths to the female diaphyseal humerus lengths estimated by the DLS

FDB Male Radius Lengths: Individual's maximum diaphyseal radius length compared to the DLS maximum diaphyseal radius length mean and standard deviation

Individual	Age (Years)	FDB Maximum Diaphyseal Radius Length (cm)	DLS Mean (cm)	DLS Standard Deviation (cm)
1233	5	12.5	13.4	.6
1397	5	13.8		
1510	5	13.6		
595	7	14.7	15.3	.7
1139	11	19.8	18.9	.9
1519	12	18.4	19.7	1

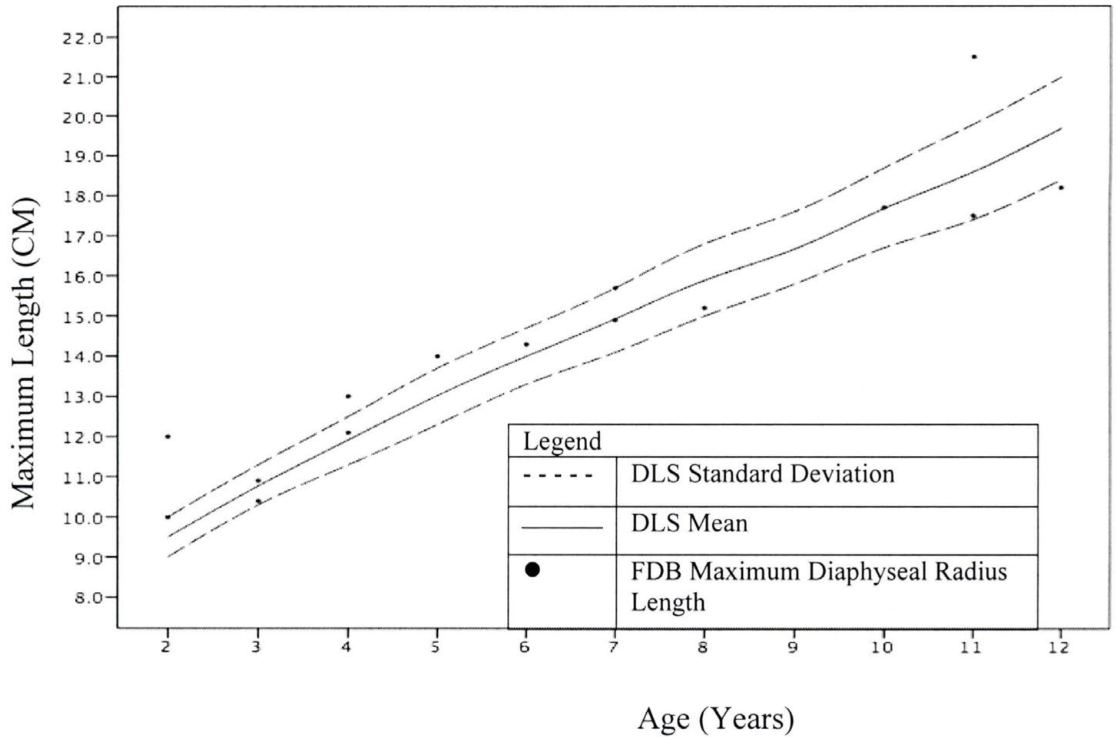


FDB Male Radius Lengths: Comparison of the FDB male diaphyseal radius lengths to the male diaphyseal radius lengths estimated by the DLS

FDB Female Radius Lengths: Individual's maximum diaphyseal radius length compared to the DLS maximum diaphyseal radius length mean and standard deviation

Individual	Age (Years)	FDB Maximum Diaphyseal Radius Length (cm)	DLS Mean (cm)	DLS Standard Deviation (cm)
219	2	10.0	9.5	.5
618	2	12.0		
615	3	10.9	10.8	.5
1185	3	10.4		
610	4	13.0	11.9	.6
1585	4	12.1		
609	5	14.0	13.0	.7
182	6	14.3	14.0	.7
1463	7	14.9	14.9	.8
1606	7	15.7		
817	8	15.2	15.9	.9
616	10	17.7	17.7	1
606	11	17.5	18.6	1.2
1509	11	21.5*		
617	12	18.2	19.7	1.3

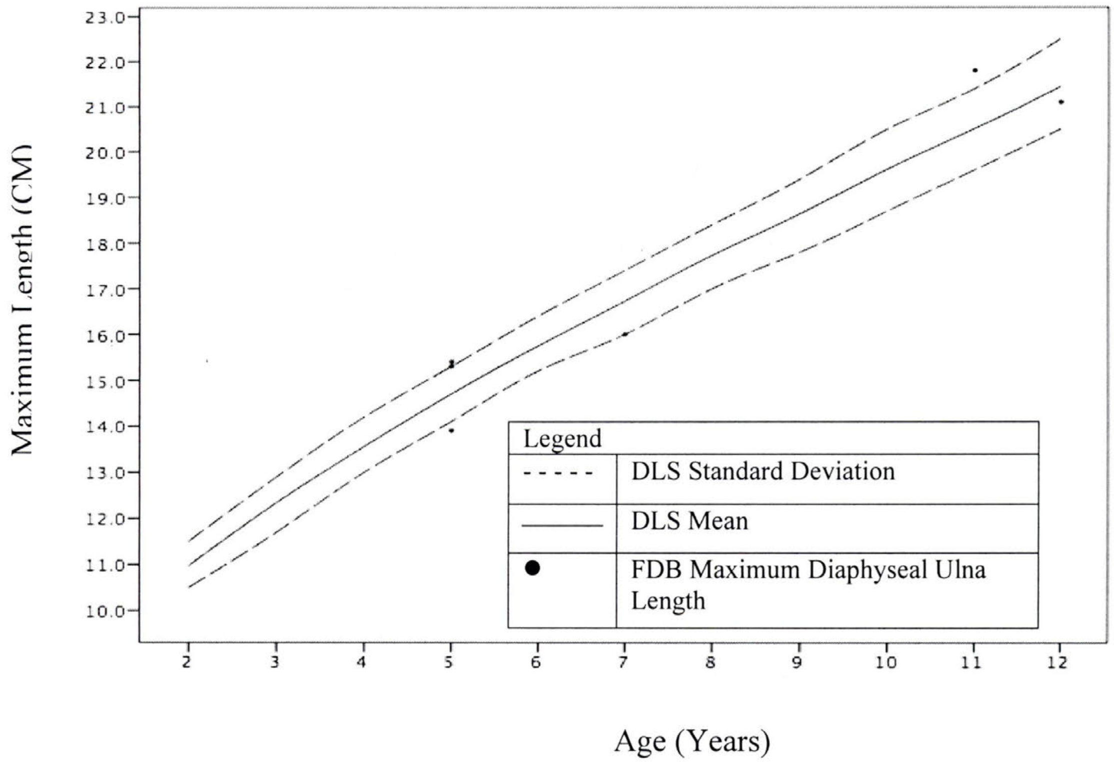
* Individual 1509's maximum diaphyseal radius length is greater than the 21 cm standard deviation upper limit for 12-year-old females in the DLS. This may be due to the inclusion of epiphyses during measurement.



FDB Female Radius Lengths: Comparison of the FDB female diaphyseal radius lengths to the female diaphyseal radius lengths estimated by the DLS

FDB Male Ulna Lengths: Individual's maximum diaphyseal ulna length compared to the DLS maximum diaphyseal ulna length mean and standard deviation

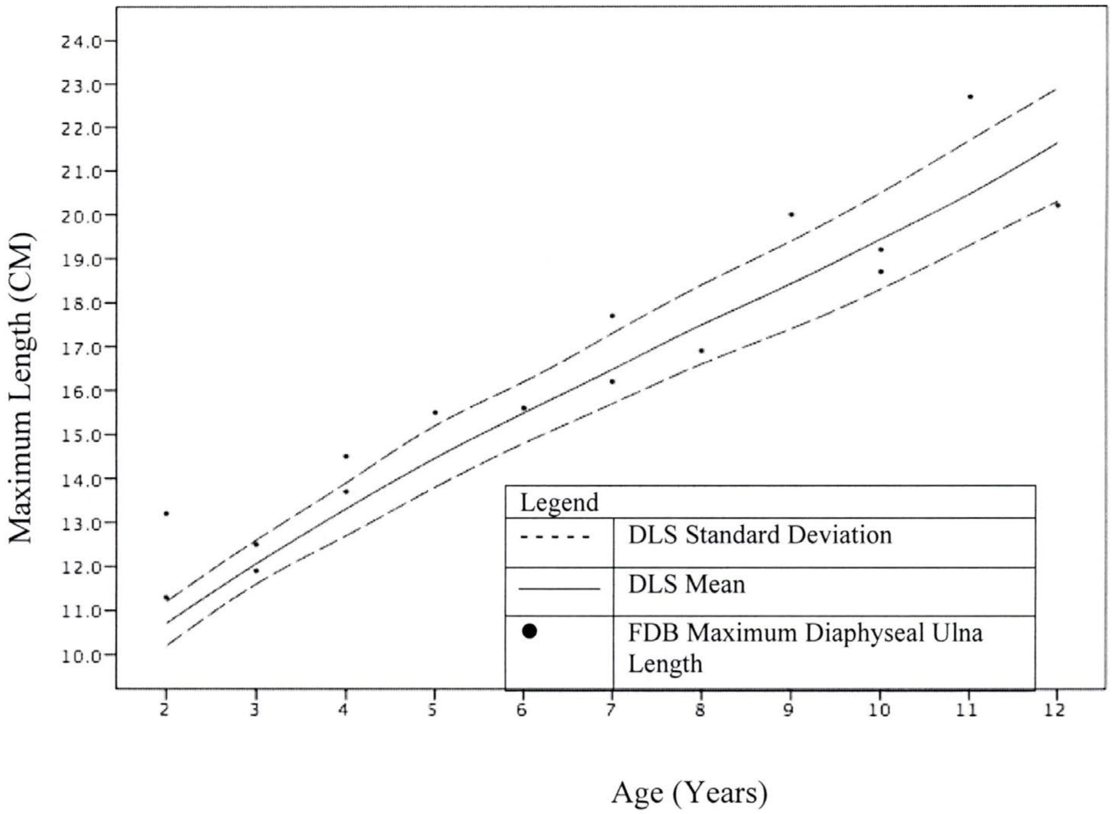
Individual	Age (Years)	FDB Maximum Diaphyseal Ulna Length (cm)	DLS Mean (cm)	DLS Standard Deviation (cm)
1233	5	13.9	14.7	.6
1397	5	15.3		
1510	5	15.4		
595	7	16.0	16.7	.7
1139	11	21.8	20.5	.9
1519	12	21.1	21.5	1



FDB Male Ulna Lengths: Comparison of the FDB male diaphyseal ulna lengths to the male diaphyseal ulna lengths estimated by the DLS

FDB Female Ulna Lengths: Individual's maximum diaphyseal ulna length compared to the DLS maximum diaphyseal ulna length mean and standard deviation

Individual	Age (Years)	FDB Maximum Diaphyseal Ulna Length (cm)	DLS Mean (cm)	DLS Standard Deviation (cm)
219	2	11.3	10.7	.5
618	2	13.2		
615	3	12.5	12.1	.5
1185	3	11.9		
610	4	14.5	13.3	.6
1585	4	13.7		
609	5	15.5	14.5	.7
182	6	15.6	15.5	.7
1463	7	16.2	16.5	.8
1606	7	17.7		
817	8	16.9	17.5	.9
607	9	20.0	18.4	1
616	10	18.7	19.4	1.1
779	10	19.2		
1509	11	22.7	20.5	1.2
617	12	20.2	21.6	1.3

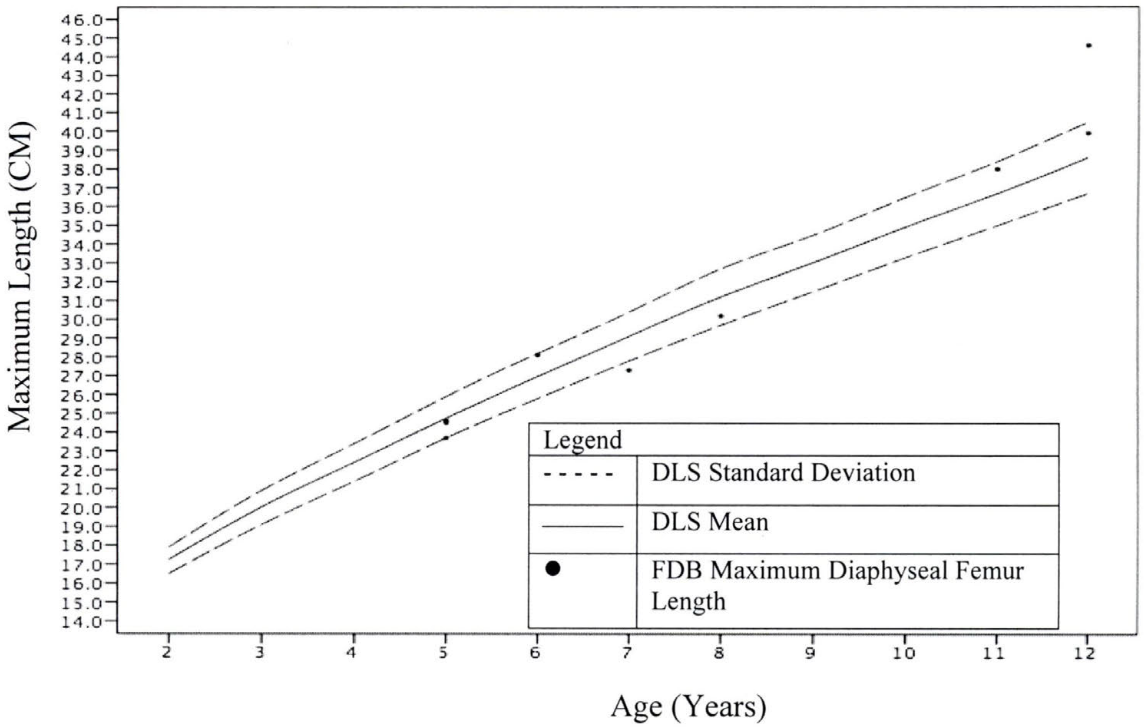


FDB Female Ulna Lengths: Comparison of the FDB female diaphyseal ulna lengths to the female diaphyseal ulna lengths estimated by the DLS

FDB Male Femur Lengths: Individual's maximum diaphyseal femur length compared to the DLS maximum diaphyseal femur length mean and standard deviation

Individual	Age (Years)	FDB Maximum Diaphyseal Femur Length (cm)	DLS Mean (cm)	DLS Standard Deviation (cm)
1233	5	23.7	24.8	1.1
1397	5	24.5		
1510	5	24.6		
605	6	28.1	27.0	1.2
595	7	27.3	29.1	1.3
604	8	30.2	31.2	1.5
1139	11	38.0	36.7	1.7
662	12	44.6*	38.6	1.9
1519	12	39.9		

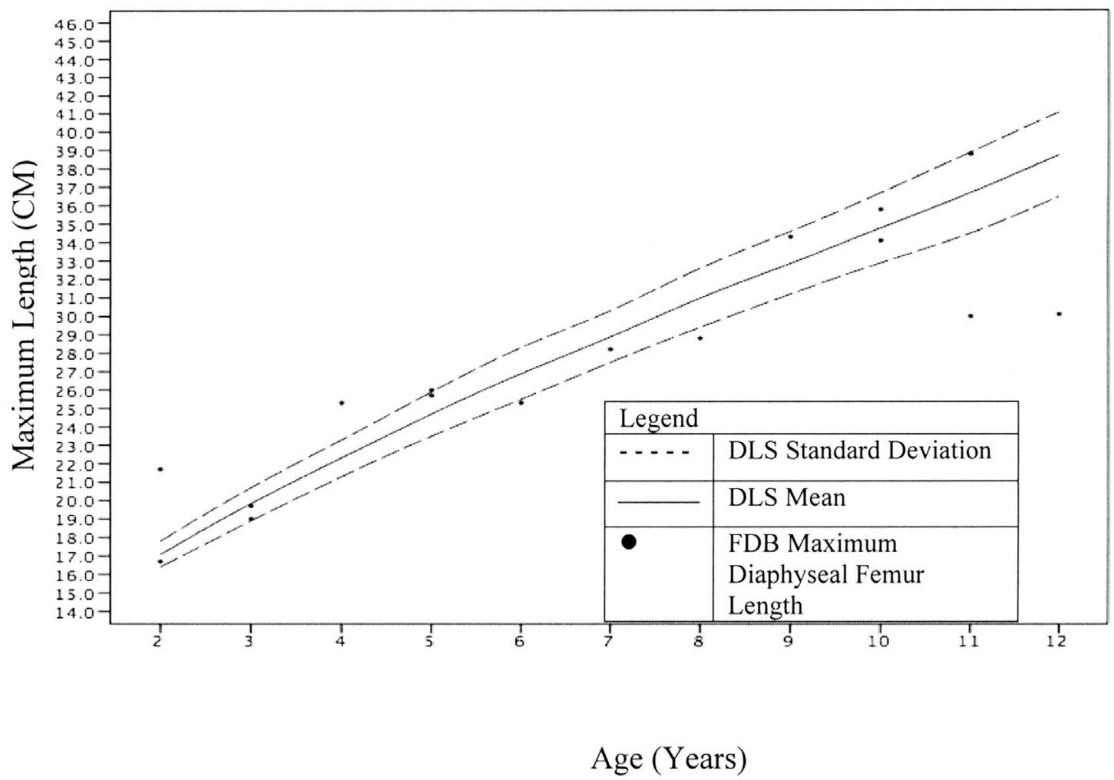
* Individual 662's maximum diaphyseal femur length is greater than the 40.5 cm standard deviation upper limit for 12-year-old males in the DLS. This may be due to the inclusion of epiphyses during measurement.



FDB Male Femur Lengths: Comparison of the FDB male diaphyseal femur lengths to the male diaphyseal femur lengths estimated by the DLS

FDB Female Femur Lengths: Individual's maximum diaphyseal femur length compared to the DLS maximum diaphyseal femur length mean and standard deviation

Individual	Age (Years)	FDB Maximum Diaphyseal Femur Length (cm)	DLS Mean (cm)	DLS Standard Deviation (cm)
219	2	16.7	17.1	.7
618	2	21.7		
615	3	19.0	19.8	.9
1185	3	19.7		
610	4	25.3	22.3	1
609	5	25.7	24.7	1.2
775	5	26.0		
182	6	25.3	26.9	1.4
1463	7	28.2	28.9	1.4
817	8	28.8	31.0	1.6
607	9	34.3	32.9	1.7
616	10	35.8	34.8	1.9
779	10	34.1		
606	11	30.0	36.7	2.2
1509	11	38.8		
617	12	30.1	38.8	2.3

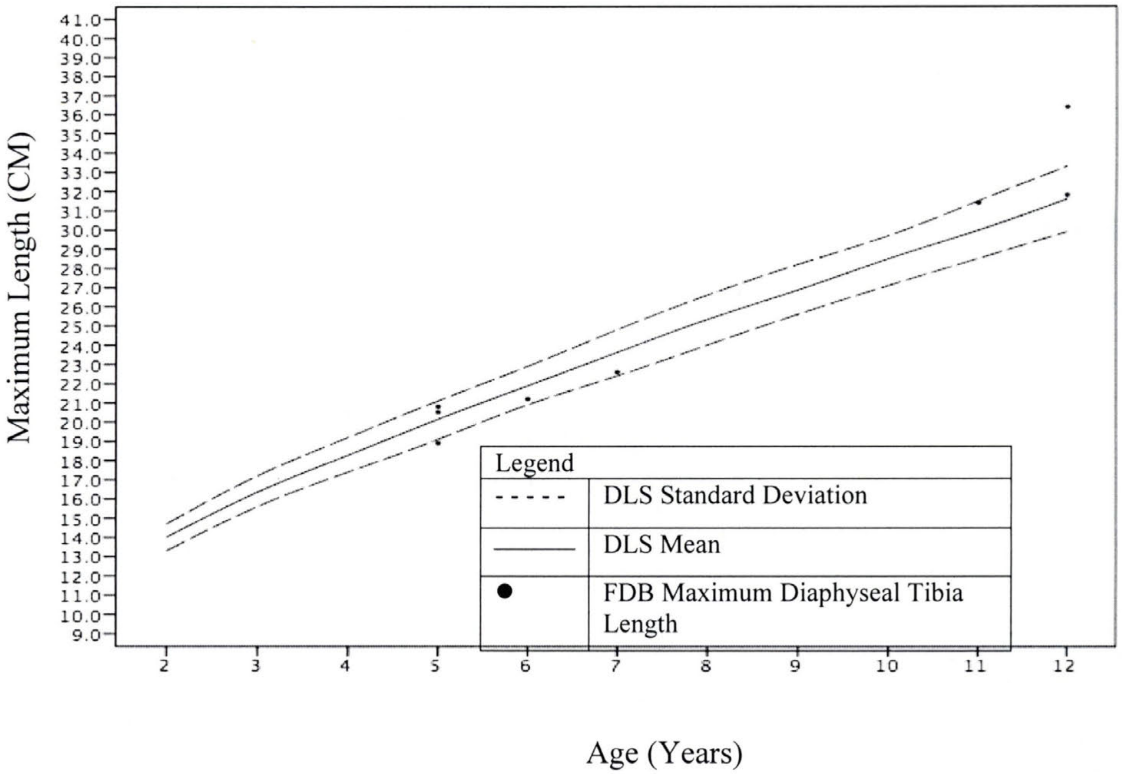


FDB Female Femur Lengths: Comparison of the FDB female diaphyseal femur lengths to the female diaphyseal femur lengths estimated by the DLS

FDB Male Tibia Lengths: Individual's maximum diaphyseal tibia length compared to the DLS maximum diaphyseal tibia length mean and standard deviation

Individual	Age (Years)	FDB Maximum Diaphyseal Tibia Length (cm)	DLS Mean (cm)	DLS Standard Deviation (cm)
1233	5	18.9	20.1	1
1397	5	20.5		
1510	5	20.8		
605	6	21.2	21.9	1
595	7	22.6	23.6	1.2
1139	11	31.4	30.0	1.5
662	12	36.4*	31.6	1.7
1519	12	31.8		

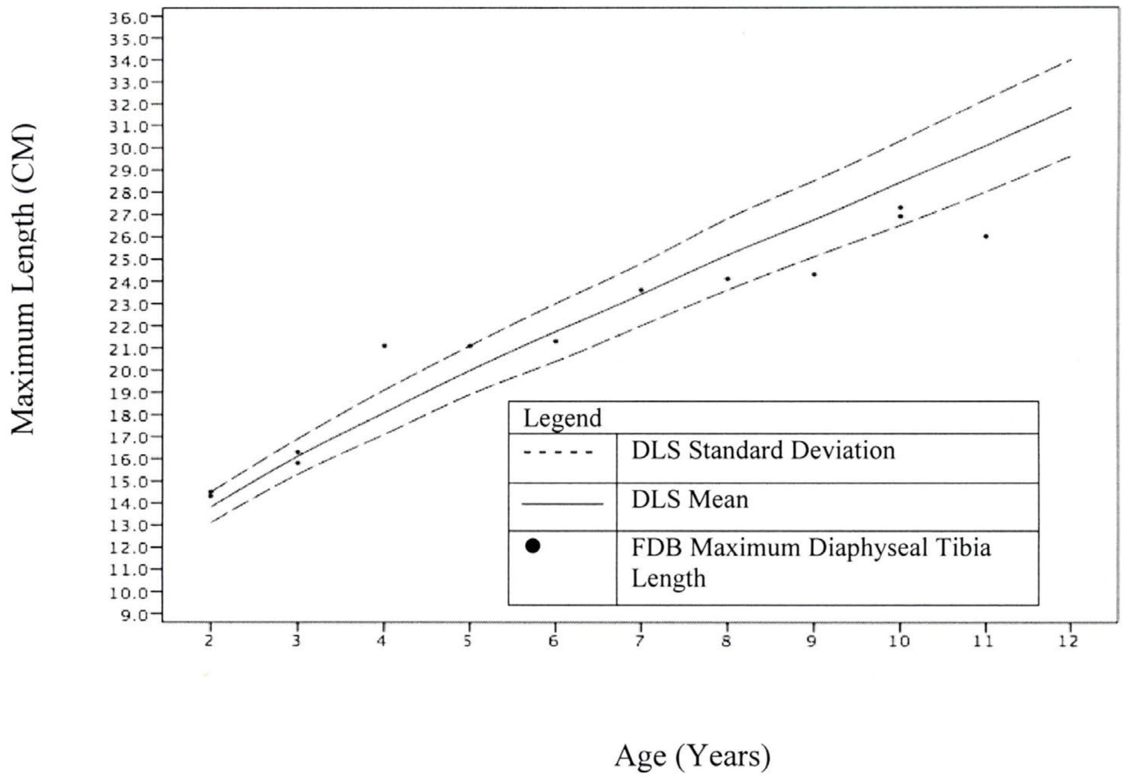
* Individual 662's maximum diaphyseal tibia length is greater than the 34.3 cm standard deviation upper limit for 12-year-old males in the DLS. This may be due to the inclusion of epiphyses during measurement



FDB Male Tibia Lengths: Comparison of the FDB male diaphyseal tibia lengths to the male diaphyseal tibia lengths estimated by the DLS

FDB Female Tibia Lengths: Individual's maximum diaphyseal tibia length compared to the DLS maximum diaphyseal tibia length mean and standard deviation

Individual	Age (Years)	FDB Maximum Diaphyseal Tibia Length (cm)	DLS Mean (cm)	DLS Standard Deviation (cm)
219	2	14.3	13.8	.7
618	2	14.5		
615	3	15.8	16.1	.8
1185	3	16.3		
610	4	21.1	18.1	1
609	5	21.1	20.0	1.1
182	6	21.3	21.7	1.3
1463	7	23.6	23.4	1.4
817	8	24.1	25.2	1.6
607	9	24.3	26.8	1.7
616	10	26.9	28.4	1.9
779	10	27.3		
219	11	26.0	30.1	2.1



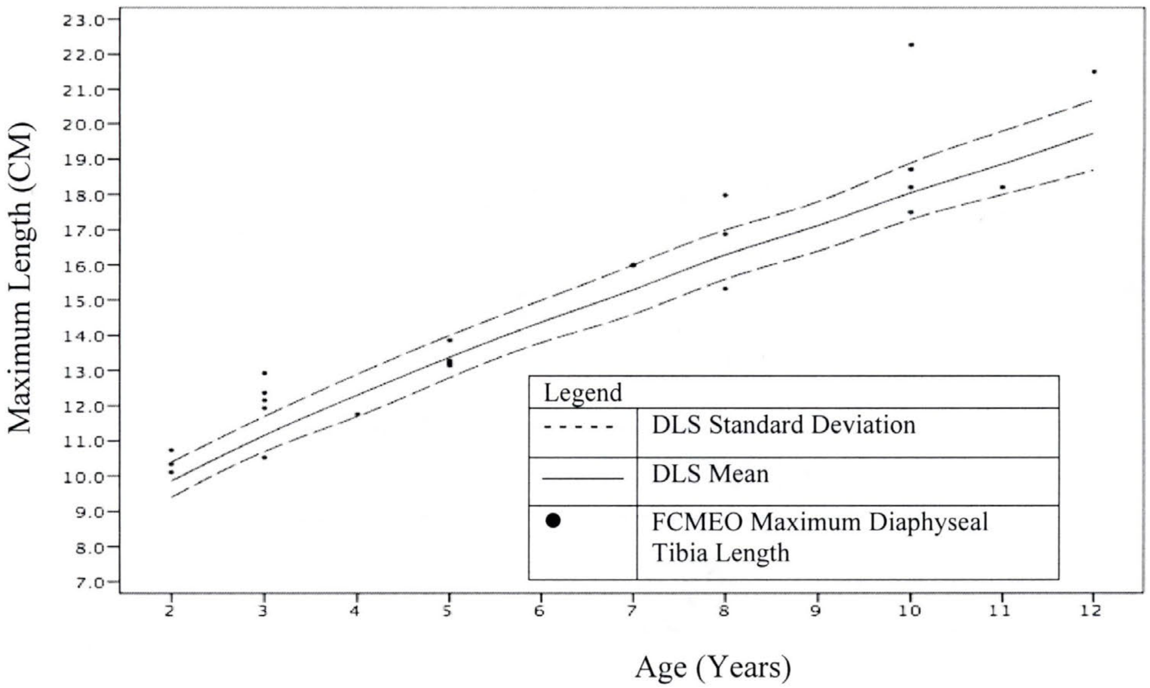
FDB Female Tibia Lengths: Comparison of the FDB female diaphyseal tibia lengths to the female diaphyseal tibia lengths estimated by the DLS

Franklin County Medical Examiner's Office

FCMEO Male Radius Lengths: Individual's maximum diaphyseal radius length compared to the DLS maximum diaphyseal radius length mean and standard deviation

Individual	Age (Years)	FCMEO Maximum Diaphyseal Radius Length (cm)	DLS Mean (cm)	DLS Standard Deviation (cm)
4	2	10.3	9.9	.5
7	2	10.7		
22	2	10.1		
9	3	12.2	11.2	.5
11	3	11.9		
13	3	12.4		
17	3	12.9		
19	3	10.5		
16	4	11.8	12.3	.6
6	5	13.3	13.4	.6
12	5	13.9		
15	5	13.2		
27	5	13.1		
2	7	16.0	15.3	.7
20	7	16.0		
1	8	16.9	16.3	.7
8	8	18.0		
21	8	15.3		
3	10	18.2	18.1	.8
5	10	17.5		
10	10	18.7		
23	10	22.3*		
25	11	18.2	18.9	.9
26	12	21.5*	19.7	1

* Individuals 23 and 26's maximum diaphyseal radius lengths are greater than the 20.7 cm standard deviation upper limit for 12-year-old males in the DLS. Since the FCMEO sample showed significant difference from the DLS standards possibly due to positive secular change, the long radius lengths may be a result of similar positive secular change.

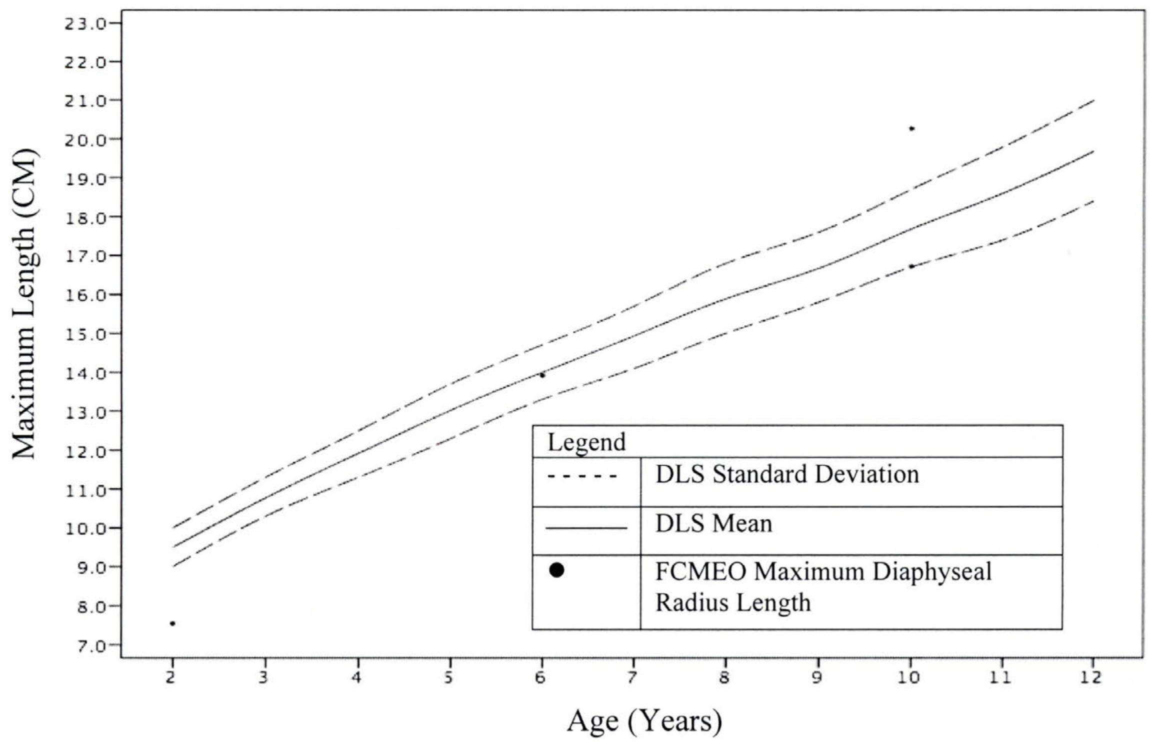


FCMEO Male Radius Lengths: Comparison of the FCMEO male diaphyseal radius lengths to the male diaphyseal radius lengths estimated by the DLS

FCMEO Female Radius Lengths: Individual's maximum diaphyseal radius length compared to the DLS maximum diaphyseal radius length mean and standard deviation

Individual	Age (Years)	FCMEO Maximum Diaphyseal Radius Length (cm)	DLS Mean (cm)	DLS Standard Deviation (cm)
18	2	7.5*	9.5	.5
24	6	13.9	14.0	.7
14	10	20.3	17.7	1
28	10	16.7		

* Individual 18's maximum diaphyseal humerus length is shorter than the 8.2 cm standard deviation lower limit for 1-year-old females in the DLS. The individual's tibia measured 1 year of age indicating that their long bones were shorter in general than the DLS.



FCMEO Female Radius Lengths: Comparison of the FCMEO female diaphyseal radius lengths to the female diaphyseal radius lengths estimated by the DLS

FCMEO Male Tibia Lengths: Individual's maximum diaphyseal tibia length compared to the DLS maximum diaphyseal tibia length mean and standard deviation

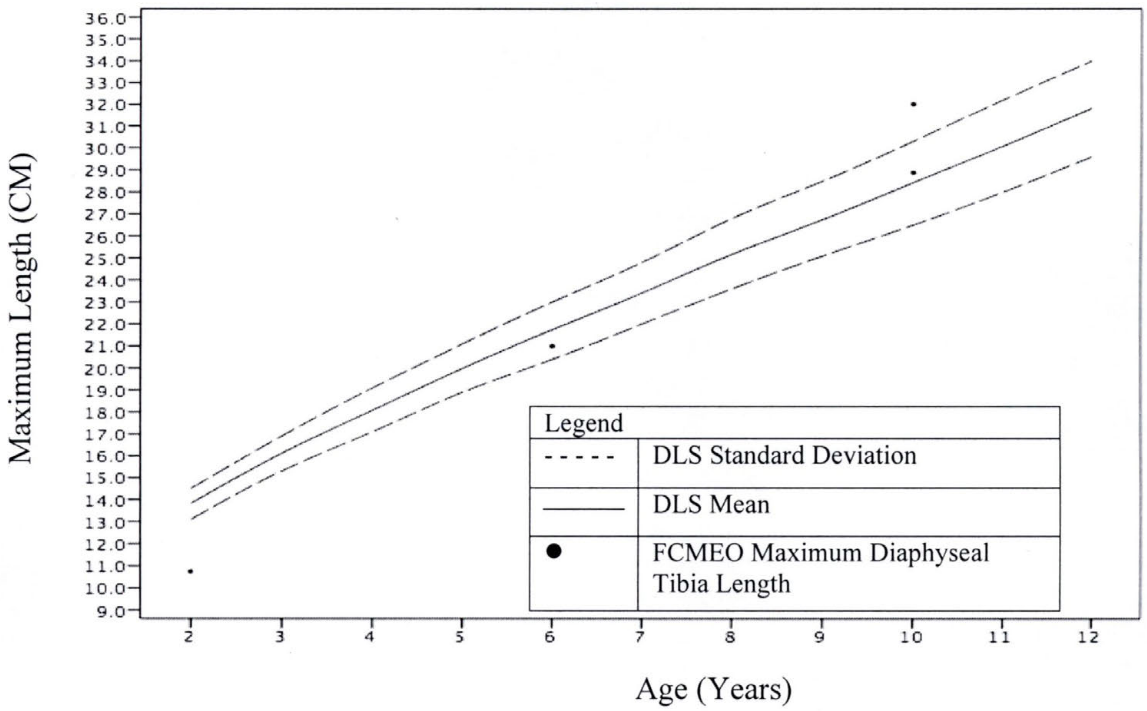
Individual	Age (Years)	FCMEO Maximum Diaphyseal Tibia Length (cm)	DLS Mean (cm)	DLS Standard Deviation (cm)
4	2	15.6	14.0	.7
7	2	15.4		
22	2	15.3		
9	3	18.1	16.4	.8
11	3	17.5		
13	3	18.4		
17	3	19.0		
19	3	15.7		
16	4	16.3	18.3	.9
6	5	20.9	20.1	1
12	5	21.4		
15	5	20.8		
27	5	20.0		
2	7	24.0	23.6	1.2
20	7	25.8		
1	8	26.2	25.3	1.3
8	8	28.8		
21	8	24.0		
3	10	31.1	28.5	1.4
5	10	31.0		
10	10	28.8		
23	10	35.0*		
26	12	33.1	31.6	1.7

* Individual 23's maximum diaphyseal tibia length is greater than the 33.4 cm standard deviation upper limit for 12-year-old males in the DLS. Since the FCMEO sample showed significant difference from the DLS standards possibly due to positive secular change, the long tibia length might be a result of similar positive secular change.

FCMEO Male Tibia Lengths: Comparison of the FCMEO male diaphyseal tibia lengths to the male diaphyseal tibia lengths estimated by the DLS

FCMEO Female Tibia Lengths: Individual's maximum diaphyseal tibia length compared to the DLS maximum diaphyseal tibia length mean and standard deviation

Individual	Age (Years)	FCMEO Maximum Diaphyseal Tibia Length (cm)	DLS Mean (cm)	DLS Standard Deviation (cm)
18	2	10.7	13.8	.7
24	6	21.0	21.7	1.3
14	10	32.0	28.4	1.9
28	10	28.9		



FCMEO Female Tibia Lengths: Comparison of the FCMEO female diaphyseal tibia lengths to the female diaphyseal tibia lengths estimated by the DLS

LITERATURE CITED

Anderson, Margaret, Marie Blais Messner, and William T. Green
1964 Distribution of Lengths of the Normal Femur and Tibia in Children rom One to Eighteen Years of Age. The Journal of Bone and Joint Surgery 46:1197-1202.

Beard, Albertine S., and Martin J. Blaser
2002 The Ecology of Height: The Effect of Microbial Transmission On Human Height. Perspectives in Biology and Medicine 45(4):475-498.

Bogin, Barry
1999 Patterns of Human Growth. Cambridge: Cambridge University Press, UK.

CDC/NCHS
2009 Mortality by underlying cause among children: US/State, 1990-2006. N.C.f.H. Statistics, ed. Hyattsville, MD: Office of Analysis and Epidemiology, National Center for Health Statistics, Centers for Disease Control and Prevention.

Cole, T.J.
2000 Secular trends in growth. Proceedings of the Nutrition Society 59:317-324.

Eveleth, Phyllis B., and James M. Tanner
1990 Worldwide variation in human growth. Cambridge: Cambridge University Press.

Gindhart, Patricia S.
1973 Growth standards for the tibia and radiusin children aged one month through eighteen years. American Journal of Physical Anthropology 39(1):41-48.

Haines, Slim
1998 A collection of useful words or what the doctor really meant when he said... Vol. 2009.

Hickman, Matthew J., and Kristen A. Hughes
2007 Medical Examiners and Coroners' Offices, 2004. B.o.J. Statistics, ed. Washington, DC.

Hoffman, J.M.
1979 Age Estimationfs from Diaphyseal Lengths: Two Months to Twelve Years. Journal of Forensic Sciences 24(2):461-469.

Hurme, V.O.
1948 Stnadards of Variation in the Eruption of the First Six Permanent Teeth. Child Development 19(1-2):213-231.

Jantz, L.M., and R.L. Jantz
1999 Secular Change in Lone Bone Length and Proportion in the United States, 1800-1970. American Journal of Physical Anthropology 110(57-67).

Jantz, Richard J., and Peer H. Moore-Jansen
1998 DATABASE FOR FORENSIC ANTHROPOLOGY IN THE UNITED STATES, 1962-1991. Knoxville, TN: Inter-university Consortium for Political and Social Research.

Kerley, Ellis R.
1976 Forensic Anthropology and Crimes Involving Children. Journal of Forensic Sciences 21(2):333-339.

Krogman, W.M.
1972 Child Growth. Ann Arbor: University of Michigan.

Lewis, Mary E.
2007 The Bioarchaeology of Children: Perspectives from Biological and Forensic Anthropology. New York: Cambridge University Press.

Lewis, Mary E., and GN Rutty
2003 The endangered child: the personal identification of children in forensic anthropology. Science and Justice 43(4):201-209.

Malina, RM, and C Bouchard
1991 Growth, Maturation, and Physical Activity. Champaign, IL: Human Kinetic Books.

Maresh, MM.
1943 Growth of Major Long Bones in Healthy Children. American Journal of Diseases of Children 66:227-257.

—
1955 Linear Growth of Long Bones of Extremities from Infancy Through Adolescence. American Journal of Diseases of Children 89:725-742.

McCammon, Robert W.
1970 Human Growth and Development. Springfield, IL: Thomas.

Pfau, Richard O. , and Paul W. Scuilli

1994 A Method for Establishing the Age of Subadults. Journal of Forensic Sciences 39(1):165-176.

Robinow, M., T.W. Richards, and M. Anderson
1947 The Eruption of Deciduous Teeth. Growth 6:127-133.

Roche, Alex F.
1992 Growth, Maturation and Body Composition: The Fels Longitudinal Study 1929-1991. Cambridge: Cambridge University Press.

Schell, Lawrence M.
1997 Culture as a stressor: A revised model of biocultural interaction. American Journal of Physical Anthropology 102(1):67-77.

Scheuer, Louise, and Sue Black
2000 Developmental Juvenile Osteology. San Diego: Academic Press.

Singh, Gopal K., and Michael D. Kogan
2007 Widening Socioeconomic Disparities in US Childhood Mortality, 1969-2000. American Journal of Public Health 97(9):1658-1665.

Smith, Shelley L., and Peter H. Buschang
2004 Variation in Longitudinal diaphyseal Long Bone Growth in Children Three to Ten Years of Age. American Journal of Human Biology 16(648-657).

Spradley, M. Katherine
2002 Age Estimation From Long Bone Lengths in Forensic Data Bank Subadults: Evidence of Growth Retardation and Implications of Under Aging. *In* American Academy of Forensic Sciences, Vol. VIII. Atlanta, Georgia: Publication Printers, Corp.

Steckel, Richard H.
1995 Stature and the Standard of Living. Journal of Economic Literature 33(4):1903-1940.

Stuart, H.C., R.B. Reed, and Associates
1959 Longitudinal Studies of Child Health and Development-Series II. Pediatrics 24:875-974.

Stull, Kyra, et al.
2009 Accuracy of Infant Metric Age Estimation Methods. *In* American Academy of Forensic Sciences. Denver, Colorado.

Tanner, James M.
1962 Growth at adolescence. Oxford: Blackwell Scientific Publications.

—
1978 Fetus Into Man. Cambridge, MA: Harvard University Press.

Ubelaker, Douglas H.
1999 Human Skeletal Remains: Excavation, Analysis, Interpretation. Washington, DC: Taraxacum.

Ulijaszek, Stanley
1998 The Secular Trend. *In* The Cambridge Encyclopedia of Human Growth and Development. S. Ulijaszek, F.E. Johnston, and M.A. Preece, eds. Pp. 395. Cambridge: Cambridge University Press.

Unit, Investigative and Operational Assistance
2008 NCIC Missing Person and Unidentified Person Statistics for 2008. F.B.o.I.N.C.I. Center, ed.

White, Tim D.
2000 Human Osteology. San Diego: Academic Press.

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