JUVENILE REMAINS: PREDICTING BODY MASS AND STATURE IN MODERN AMERICAN POPULATIONS

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ABSTRACT

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There are increasing numbers of unidentified persons in the U.S. and abroad. To generate positive identifications, forensic anthropologists and others working in the medicolegal field employ a variety of methods to produce biological profiles to match to case files and missing persons databases. Body mass, and stature are two important components of a biological profile, and both can be estimated using regression formulae derived from skeletal metrics. In cases of unidentified juvenile remains, these are particularly important metrics, as it is difficult or impossible to determine sex in prepubescent remains, and the quality of ancestry estimation is currently under debate in the anthropological community. This study presents new formulae for estimating juvenile body mass, and stature utilizing femoral measurements, and medical records from a modern American population. In this study, organizational systems such as age class and sex were less strongly associated with osteometric measurements. However, this was likely because of the smaller sample sizes, given that standard errors were less when taking these organizational systems into account. Additionally, race, and ethnicity as organizational systems are explored in this thesis.

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To Depression and Anxiety –

My unfortunate constant companions, you are stuck to me much like barnacles or perhaps an Alien face sucker. Despite your best efforts, this process has made me furiously happy.

To Self-Doubt –

I hope you choke.

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INTRODUCTION

Conservative estimates by the National Institute for Justice indicate that there are approximately 40,000 unidentified remains of adults and juveniles in the United States of America at any given time. Nationwide, 4,400 unidentified remains are recovered annually, and at the end of each year 1,000 of those remains are still without names (Ritter, 2007). The Bureau of Justice Statistics reported that less than half of medical examiner and coroners' offices have policies requiring retention of records, such as x-rays, fingerprints, or DNA, associated with unidentified decedents (2007). Of the 1,000 unidentified decedents in the United States that become cold cases every year, 600 undergo final disposition, such as burial or cremation (Hickman, Hughes, Storm, & Ropero-Miller, Ph.D., 2007). The sheer volume of the casework is sobering; its complexity compounded due to overlapping resources that not all law enforcement agencies are aware of or have the resources to access. In particular, some law enforcement agencies do not have knowledge of, or access to their state's missing persons clearinghouse or the four applicable federal databases (Ritter, 2007). One of these databases, the National Crime Information Center (NCIC), reported that as of 2013 the United States only had 8,045 EUD or "unidentified deceased persons" (Ritter, 2007; NCIC Missing Person and Unidentified Person Statistics for 2013, 2013). The incompleteness of their report, despite the publication of the Bureau of Justice Statistic's census almost a decade prior, illustrates how each federal database is hobbled by its dependence on local and federal law enforcement agencies for its case information.

Current statistics suggest the number of unidentified individuals in the United States will continue to grow in the immediate future. To truly address the issue, it must be considered thoughtfully as both a medicolegal issue as well as one of social justice. It would not be inaccurate or hyperbolic to describe the accumulation of tens of thousands of unidentified human remains "a mass disaster over time" (Ritter, 2007). Practicing anthropologists have only recently begun to address such cases with human rights models successfully applied to war crimes, genocides, extrajudicial killings, and forced disappearances utilized in the Global South (Baraybar & Blackwell, 2014; Kimmerle, 2014).

Anthropologists working in the medicolegal context or otherwise collaborating with law enforcement agencies must evaluate the tools currently available to them in the identification of unknown persons considering the staggering task associated with reducing the number of unidentified decedents. Radiographs, fingerprints, and genetic profiles can be incredibly useful tools when attempting to identify an unknown person (Ritter, 2007). However, each requires a starting point. A deoxyribonucleic acid (DNA) profile (or radiograph or fingerprint) is only useful when it can be compared to the profile of a known individual. If a set of unidentified remains does not provide investigators with enough information to create a reasonably small pool of potential "matches", the remains will stay unidentified. Thus, when working with unidentified remains, it is imperative that as much information is collected and reported to investigators as possible. By creating more accurate biological profiles, the work many forensic anthropologists engage in can narrow down the points of comparison. A biological profile, in the field of forensic anthropology, details the skeletal traits of an individual, providing important identifying information including sex, approximate age at time of death, ancestry, stature, body mass, and uniquely identifying characteristics, such as a healed humoral fracture.

Complete biological profiles for juvenile remains have repeatedly proven to be particularly difficult to produce, thereby limiting their successful identification. As of April 2017, the National Missing and Unidentified Persons System included 11,409 open cases – a fraction of the unidentified remains cases in the United States. Of the unidentified remains listed in the database, 611 belonged to juveniles with age classes listed as “fetus”, “infant”, “preadolescent”, “adolescent”, and “late teen/young adult” (National missing and Unidentified Persons System, 2017). It is difficult or impossible to determine the biological sex of prepubescent juvenile remains and with the reliability of ancestry estimation in question, anthropologists are left with age at time of death, and stature and body mass estimations, along with skeletal particularities, for constructing biological profiles (Kimmerle, 2014). Refining these metrics for skeletonized human remains has the potential to lead to a greater number of identifications.

Juvenile stature and body mass were originally estimated using formulae based on adult remains. This practice changed after repeated questioning by Telkka, Palkama, and Virtama (1962), and Feldesman (1992). Telkka et al. began the conversation regarding juvenile body mass and stature estimation after numerous methods were produced for adults after World War II and the Korean War, but none for children (Telkka, Palkama, & Virtama, 1962). Feldesman’s exploration of the femur/stature ratio furthered the dialogue in the anthropological community and has continued over the better part of three decades (Feldesman M. R., 1992). Since then, anthropologists have examined juvenile long bones, particularly femora, tali, and humeri, in both modern and archaeological populations, and both in dry bones and radiographs, in attempts to create the most accurate and precise body mass and stature estimations.

A pinnacle study on childhood growth and development, the Denver Growth Study, followed the growth of a group of children in mid-twentieth century Denver through longitudinally collected radiographs and associated personal health information (PHI) (Maresh, 1970). Ruff (2007) used data from the Denver Growth Study to measure the femur, tibia, humerus, and radius and calculate regression formulae for the estimation of stature and body mass in various juvenile age classes (Ruff, 2007)

More recent studies attempted to eliminate the use of age classes since they can often be cumbersome to use – it is not uncommon for age estimations to be inexact. Robbins Schug, Cowgill, Sciulli, and Blatt (2013) successfully removed the age classes in their study, which relied on the same dataset as Ruff and applied the resulting estimation formulae to an independent subject population of cadavers from Franklin County, Ohio.

The present study builds upon the work of previous studies exploring how to most accurately model body mass and stature from skeletal remains in juveniles. A radiograph-based analysis of juvenile femora was performed and femoral metrics were considered with respect to individual height and weight. Age and sex classes were examined, and found to be cumbersome organizational systems but necessary when minimizing error. This study’s sample population included a more diverse subject population in terms of ancestry than previous studies. The resulting regression formulae for body mass and stature were considered with respect to previous studies and the resulting implications.

LITERATURE REVIEW

Body mass and stature are key characteristics for any biological profile. As such, it is imperative that forensic practitioners have appropriate methodologies for measuring these features (Wilson, Hermann, & Jantz, 2010). Scholars across fields have attempted to create mathematical formulae derived from long bone lengths, weight, and height measurements since the late nineteenth century for these explicit purposes (Rollet, 1888; Pearson, 1899). The constant refinement of methods for various populations continues into modern studies (Ahmed, 2013; Dupertuis & Hadden, 1951; Feldesman M. R., 1992; Fully, 1956; Inamori-Kawamoto, et al., 2016; Kimura, 1992; Maresh, 1970; Robbins, Sciulli, & Blatt, 2010; Robbins Schug, Cowgill, Sciulli, & Blatt, 2013; Ruff, 2007; Smith, 2007; Telkka et al., 1962; Trotter & Gleser, 1952; Wilson et al., 2010).

The structure of these studies have evolved with time and produced increasingly more complex, realistic relationships between the skeletal materials examined after death and life approximations. Simple stature ratios examining the correlation between long bones and height have become regression formulae where height is considered a dependent variable in association with the independent variable or long bones measurements, ultimately producing a linear relationship (Lacey, 1998). Body mass regressions studies, although limited in number, include everything from midshaft geometry to femoral head diameter (Robbins Schug, Cowgill, Sciulli, & Blatt, 2013).

Since the first publication of a body mass and stature formulae, biological anthropologists have constantly vied to reveal more accurate and precise equations with updates hotly debated in letters to the editors in academic journals (Bass, 2005). This has been particularly true of juvenile formulae. Although originally glossed over in early studies, many modern stature and body mass estimations focus on the complex puzzle of estimating these metrics when relying on a population still growing and developing!

Body Mass and Stature Estimations

Early adult studies

Rollet (1888) published one the earliest attempts to estimate adult stature from long bone lengths. His sample population consisted of 100 French cadavers – 50 females, and 50 males, ranging in age from 24 to 99 years old. Rollet collected height measurements from the cadavers within one week of death. This was followed by repeated measurements of the long bones – humerus, radius, ulna, femur, tibia, and fibula – first in a "wet" state. The long bones were measured again after a period of 8 to 10 months having completed the process of maceration and "drying out". Rollet noted that a difference in lengths between the wet and dry bones – on average, the bones had lost 2 mm during the natural drying process. Utilizing the measurements of the long bones in their wet and dry states, in conjunction with height, Rollet produced sex based stature formulae – or a formula for females and a formula for males. Because forensic cases often involve dry bone, Rollet's study corrected for the difference between dry bone and wet, living bone (Rollet, 1888).

While noting the limiting nature of the small sample size, Pearson (1899) utilized Rollet's (1888) height and long bone lengths, eliminating measurements not strictly indicated as originating from a long bone on the right side of a subject, except where missing. In an attempt to eliminate effects of age on the skeleton, the study only used the standard deviations and coefficients of correlation from the Rollet's study. Pearson departed from the simple ratio proposed by Rollet and introduced regression formulae into the study of human stature (Dupertuis & Hadden, 1951; Pearson, 1899; Rollet, 1888; Trotter & Gleser, 1952). When tested, the sex based regression formulae produced a mean standard error of approximately 2 cm. However, in at least one case of a 47-year-old male, standard error was as high as 8 cm (Pearson, 1899). A total of twenty formulae – ten per sex – were produced, testing various combinations of the long bones to determine the most accurate predictor of stature (see Table 1). A formula was produced for each individual bone, where the first letter of the bone represented its measurement (e.g. F for femur), plus a formula for the combining of bones of the upper limb (individually and separately), a formula for the bones of the lower limb (individually and separately), a formula adding the humerus and femur separately, and finally, a formula including all bones of both upper and lower limbs.

When testing the formulae, noticeable sex based patterns emerged. For both sexes, the formulae with the fewest probable errors included all four bones. Additionally, the formulae relying solely on the radius introduced the most errors for both sexes. However, male formulae involving the humerus were more reliable than formulae relying on the tibia; the opposite was true for females.

Pearson contextualized his findings as far from the “final” word on the subject. He noted that 50 subjects per sex was not a substantial enough sample population to draw any definitive conclusions. Furthermore, he cautioned against utilizing the formulae outside of the French population from which it was derived (Pearson, 1899).

Table 1: Pearson (1899) Formulae by bone for adults

Formulae for the Reconstruction of the	Stature as Corpse
Male	Female
S=81.231+1.880F	S=73.163+1.945F
S=70.714+2.894H	S=72.046+2.754H
S=78.807+2.376T	S=75.396+2.353T
S=86.465+3.271R	S=82.189+3.343R
S=71.164+1.159(F+T)	S=69.525+1.126(F+T)
S=71.329+1.221F+1.080T	S=69.939+1.117F+1.125T
S=67.025+1.730(H+R)	S=70.585+1.628(H+R)
S=69.870+2.769H+.195R	S=71.122+2.582H+.281R
S=68.287+1.030F+1.557H	S=67.763+1.339F+1.027H
S=66.918+.913F+.600T+1.225H-.187R	S=67.810+.782F+1.120T+1.059H-.711R

Dupertuis and Hadden (1951) proposed a series of revisions to Pearson’s formulae, employing a larger sample population pulled from the Todd Osteological Collection at the School of Medicine at Western Reserve University (Dupertuis & Hadden, 1951; Pearson, 1899). The Todd Collection was assembled by Professor T. Wingate Todd and is made up of 3,000 cadaver derived skeletons, collected between 1912 and 1938 (Collections & Database: Cleveland Museum of Natural History, 2017). Dupertuis and Hadden utilized 100 white males, and 100 white females, 20 to 65 years old, and 100 African American males and 100 African American females, 20 to 45 years old, from the collection. Of the white cadaver population, the authors characterize the subjects as largely foreign born or first generation American, and generally including German heritage. The African American cadaver population is described as mostly southern born Americans, largely hailing from Alabama. Both populations are described by Todd to the authors as not paupers, but the “indigent poor”.

The researchers had a single observer record long bone lengths for both the left and right sides, however, only the right measurements were ultimately used. Basing their calculations on Pearson’s (1899) models, Dupertuis and Hadden (1951) found the mean value for the height of all four cadaver populations. The mean value was then used with the long bone measurements to produce regression formulae to estimate stature in white males, white females, African American males, and African American females (see Tables 2 and 3). In creating, analyzing, and comparing these formulae, to those of Pearson (1899), Dupertuis and Hadden noted that the American populations were significantly taller on average that the previously tested French population. Their standard error ranged from .2256 to .2819 compared to Pearson’s standard error, ranging from .3047 to .3058 (Dupertuis & Hadden, 1951; Pearson, 1899). The lowest standard error was reported for the white cadaver populations. Also, this study reported again that the radius was the least reliable estimator of stature.

In addition to the sex based, racial class regression formulae, general sex based regression formulae were produced, where the data for same sex cadaver populations were combined. When compared to the racial class formulae, results were mixed. The general formulae worked better for both white males and females than the white specific formulae and were comparable to the racial class formulae for the African American subjects. Dupertuis and Hadden (1951) also checked their race class formulae against the other cadaver population and found that African American specific formulae in some instances worked better for white subjects than the general or white specific formulae, leaving questions regarding the accuracy of racial classes.

Table 2: Dupertuis and Hadden (1951) Formulae by bone for white adults

Formulae for the Reconstruction of stature	from long bones
White Males	White Females
S=77.048+2.116F	S=62.872+2.322F
S=92.766+2.178T	S=71.652+2.635T
S=98.341+2.270H	S=56.727+3.448H
S=88.881+3.449R	S=68.238+4.258R
S=84.898+1.072(F+T)	S=57.872+1.354 (F+T)
S=87.543+1.492(H+R)	S=42.386+2.280(H+R)
S=76.201+1.330F+0.991T	S=60.377+1.472F+1.133T
S=82.831+0.907H+2.474R	S=53.187+2.213H+1.877R
S=78.261+2.129F-0.055H	S=55.179+1.835F+0.935H
S=88.581+1.945T+0.524R	S=64.702+2.089T+1.169R
S=52.618+1.512F+0.927T-0.490H+1.386R	S=56.660-1.267F+0.992T+0.449H+0.164R

Table 3: Dupertuis and Hadden (1951) Formulae for African American adults

Formulae for the Reconstruction of stature	from long bones
African American Males	African American Females
S=55.021+2.540F	S=54.235+2.498F
S=72.123+2.614T	S=72.391+2.521T
S=50.263+3.709H	S=69.978+3.035H
S=69.168+4.040R	S=74.906+3.761R
S=52.702+1.411(F+T)	S=70.584+1.165(F+T)
S=57.601+1.962(H+R)	S=61.982+1.866(H+R)
S=54.438+1.615F+1.123T	S=52.989+2.112F+0.501T
S=48.275+2.182H+2.032R	S=62.402+1.906H+1.769R
S=48.802+2.175F+0.696H	S=55.103+2.517F-0.033H
S=67.964+2.260T+0.689R	S=66.005+2.076T+0.952R
S=53.873+1.637F+1.101T+0.084H-0.093R	S=53.3442+2.201F+0.359T-0.663H+0.930R

The following year, Trotter and Gleser (1952) also published a study including sex based racial class regression formulae. Their study continues to be the standard for adult stature estimations in the United States (Wilson, Hermann, & Jantz, 2010).

Trotter and Gleser (1952) created a sample population from two sources. The first source includes the remains of American military personnel from the Pacific theater during World War II. As such, all were young males whose bones dried naturally from shallow burials. Stature was recorded at the time of their enlistment. The record of living stature, as opposed to cadaver stature, makes this inclusion different to prior studies. However, it also introduced another type of error – height measurements were recorded by an unknowable number of observers, introducing interobserver error. The military sample population included 1,115 white males, and 85 African American males. Ages ranged from 17 to 47 years old. The second source for the sample population was the Terry Skeletal Collection. Currently housed at the Smithsonian, the Terry Collection was assembled by Professor Robert J. Terry, and eventually continued by Dr. Mildred Trotter, over the course of the twentieth century until it eventually included over 2,000 skeletons (Hunt, 2017). The Terry Collection sample population included documentation indicating cadaver length. It was comprised of 255 white males, 360 white females, 63 African American males, and 177 African American females. Terry Collection subjects ranged in age from 19 to 99 years old.

Trotter and Gleser (1951) excluded military personnel younger than 18 years old from the final sample population. An age correction for bone loss was applied to all Terry Collection subjects over of 30 years old at time of death. The length of the humerus, radius, ulna, femur (bicondylar and maximum), tibia (ordinary and maximum), and fibula were all measured. The average length of bone pairs was used (i.e. when a subject included both a right and left humerus or other long bone, the average was utilized rather than either individual measurement) to minimize estimation error. Regression equations were calculated similarly to Pearson (1899), relying on a linear relationship between long bone length and stature. However, the authors included the unique criteria of living stature via the military personnel sample population, a correction for the effects of age on stature, and test of "validity…by application to a different sample of reasonably large size" (Trotter & Gleser, 1951 p. 473). The resulting formulae suggest that the living stature measurements introduce less error variance (see Tables 4 and 5). Standard error for the white military personnel population ranged from 3.27 to 4.32 cm. For comparison, the analogous population from the Terry Collection ranged from 3.69 to 4.99 cm. Trotter and Gelser (1951) explored the inclusion of multiple long bones in any given equation. They argued that the smallest standard errors were consistently associated with formulae based on bones of the lower limb. Correlations between formulae utilizing just two long bones versus formulae utilizing four long bones were similarly high, indicating that no precision was gained by including additional bones. Given that the fibula and ulna are frequently broken or missing in the context of recovered remains, Trotter and Gleser argued against formulae including either and for formulae relying on the two most reliable measurements – maximum femoral length and maximum tibial length (Trotter & Gleser, 1952).

Table 4: Trotter & Gleser (1952) Formulae and standard error for respective white sample populations by bone where $_m$ means maximum length measurement

White					
Male Military Personnel	SE	Male Terry Collection	SE	Female Terry Collection	SE
3.08H+70.45	4.05	3.10H+70.00	4.78	3.36H+60.47	4.45
3.78R+79.01	4.32	4.01R+74.43	4.97	4.74R+57.43	4.24
3.70U+74.05	4.32	3.81U+72.40	4.99	4.27U+60.26	4.30
2.42Fe+60.37	3.27	2.61Fe+53.76	3.69	2.48Fe+56.93	3.78
$2.38Fe_m+61.41$	3.27	$2.58Fe_m+54.79$	3.69	$2.47Fe_m+56.60$	3.72
$2.52T_m+78.62$	3.37	$2.79T_m+70.81$	4.13	$2.90T_m+64.03$	3.66
2.60T+78.10	3.30	2.82T+72.62	4.15	2.95T+64.83	3.82
2.68Fi+71.78	3.29	2.86Fi+67.09	4.17	2.93Fi+62.11	3.57

Table 5: Trotter & Gleser (1952) Formulae and standard error for respective African American sample populations by bone where $_m$ means maximum length measurement

African American					
Male Military Personnel	SE	Male Terry Collection	SE	Female Terry Collection	SE
3.26H+62.10	4.43	3.35H+60.75	4.39	3.08H+67.17	4.25
3.42R+81.56	4.30	3.78R+74.40	4.79	2.75R+97.01	5.05
3.26U+79.29	4.42	3.63U+71.66	4.96	3.31U+77.88	4.83
2.14Fe+69.74	3.93	2.15Fe+72.69	4.47	2.30Fe+62.39	3.58
$2.11Fe_m+70.35$	3.94	$2.11Fe_m+73.84$	4.49	$2.28Fe_m+62.26$	3.41
$2.19T_m+86.02$	3.78	$2.60T_m+73.23$	4.02	$2.45T_m+75.15$	3.70
2.17T+88.83	3.82	2.64T+74.46	4.05	2.48T+76.27	3.83
2.19Fi+85.65	4.08	2.68Fi+69.51	4.00	2.49Fi+73.40	3.80

The anatomical method

An alternative method for determining stature is the anatomical method. In 1956, Fully also responded to the need for accurate stature formulae resulting from World War II. Fully (1956) produced a formula, simple and elegant in design. It sums all the height contributing bones in the body, and applies a correction for cartilage. Fully's method or includes the height of the skull from basion to bregma, the articulated height of the axis and atlas (cervical vertebrae 1 and 2), the body height of the third cervical vertebra (C3) through the fifth lumbar vertebra (L5), to the first sacral vertebra (S1), plus the length of the femur and tibia, and the height of the calcaneus (Fully, 1956).

Evaluating methods for adults

Maijanen (2009) studied eight versions of the anatomical method. The author then compared their results to the typically used long bone regressions from Trotter and Gleser (1952) and another less used one, from Ousley. Maijanen's review relied on a limited population (N=34) of white males between the ages of 27-59 from the W. M. Bass Donated Skeletal Collection. Comparing both anatomical and long bone regression methods, Maijanen found that though the anatomical methods were labor intensive and required an almost complete skeleton, they were on average more likely to produce accurate stature estimations. Additionally, they were more accurate when dealing with "atypical" body ratios. However, both methods of stature prediction routinely underestimated stature, even after a cadaver height correction was applied (Maijanen, 2009).

In another study, Wilson, Herrmann, and Jantz (2010) examined the long-held belief that the much-used Trotter and Gleser (1952) stature equations (developed for adults) were reliable. Given modern secular trends (i.e. patterns occurring over long periods of time), it was argued that the dated remains of the original skeletal sample could not accurately reflect modern populations. For example, an often-cited critique is that the

Trotter and Gleser equations derived measurements for women from the Terry Collection, which has an average birthdate between 1850 and 1900. This era happens to be one of the shortest for Americans on record, meaning the height derived from those skeletons cannot accurately reflect more modern populations, which are becoming increasingly taller.

During their test and critique of the Trotter and Gleser equations, the authors utilized the National Institute of Justice Database for Forensic Anthropology (FSTAT), and the Forensic Anthropology Data Bank to provide updated long bone regression formulae, and confidence intervals that reflected the heights of modern populations. Postcranial measurements from 242 individuals, were utilized in conjunction with biographical information, such as sex, age, and ancestry. Ancestry was limited to those identified as African American or white. Their proposed formulae produced better overall results for African Americans and whites, producing lower standard deviations for all long bone measurements relied on – humerus, femur, combined femur and tibia – than the previous study. The standard deviations ranged from 3.56 to 6.75 – a smaller range when compared to the standard deviation from Trotter and Gleser (1952), 3.53 to 7.65. The authors ultimately argue that estimating body mass or stature is a moving target for forensic anthropologists given the effects of secular trends and migrating populations (Wilson, Hermann, & Jantz, 2010).

Non-femur related methods for adults

Starting in the early revisions of adult stature and body mass formulae of the late 1980s, anthropologists have attempted to expand the stature and body mass equations beyond the cumbersome complete skeleton methods and the often less-than-accurate femoral measurement methods for almost three decades. The upper limb, and the articulated height of the calcaneus and talus are proposed options for incomplete skeletons. Some studies have even looked at the hand.

Ahmed (2013) measured the right upper hand and stature of 200 right-handed Sudanese adults, aged 25 to 30 years old – 100 males and 100 females. Skeletal measurements included humeral length, ulnar length, wrist breadth, hand length, and hand breadth. All five measurements were conducted on the left side of the subject and performed three times. During analysis, Ahmed created two sex specific groups and compared the equality of the measurements and discovered that all the measurements were significantly larger for male subjects than female subjects ($p<0.001$). In both sex classes, the study indicated a highly significant and positive correlation between upper limb measurements and stature, with ulnar length having the strongest correlation to stature ($R=0.725$ for males; $R=0.722$ for females) (Ahmed, 2013).

Inamori-Kawamoto et al. similarly departed from standard regression of femoral measurements by utilizing computed tomography (CT) of the calcaneus and talus (2016). Three-dimensional images of feet were collected from 179 Japanese adults, over the age of 15 years old – 100 males and 79 females. All CTs were postmortem scans routinely created in conjunction with autopsy, and were free of obvious fracture, destruction, decomposition, and osteoarthritis. Utilizing mass volume, mean CT value, and total CT value of the talus and calcaneus, Inamori-Kawamoto et al. found a correlation between age-dependent decreases in bone density in both sexes, particularly in participants over the age of 60 years old ($p<0.001$). Decreases in bone density appeared to be further compounded by sex, as women suffered from greater density loss. Furthermore, there were moderate correlations between body height and the mass volumes of talus and calcaneus ($R=0.71$-0.78; $p<0.001$). However, the correlation between talus and body weight in women was insufficient for identification purposes ($R=0.41$-0.61; $p<0.001$). Despite the current inability to accurately estimate body mass from tali, the study reveals the exciting ways new technology can be incorporated into future studies, while also establishing correlations between bone density, body height, and body weight from the talus and calcaneus, similar to correlations already accepted (Inamori-Kawamoto, et al., 2016).

Emergence of juvenile formulae

Sub-adult body mass and stature calculations present their own unique set of problems, independent (and deeply intertwined with) those associated with adult formulae.

Telkka, Palkama, and Virtama (1962) addressed the issue of lacking juvenile stature estimate formulae with their study of radiographs of 3,848 long bones (humerus, radius, ulna, femur, tibia, fibula) in juveniles from ca. 1 to 15 years old. All radiographs were from the Children’s Clinic at University Central Hospital of Helsinnki, Sweden from

1950 to 1960. All images utilized were deemed “normal” – any known conditions potentially affecting the normal growth of the limbs were omitted from the subject sample. Images were examined with a backlit frame designed to illuminate radiographs or a “viewing box”, and measured. Telkka et al. applied a 1 to 2% variation correction to all measurements. All long bones were measured from their most distal to most proximal points, excluding epiphyses, to obtain maximum diaphyseal length. An ordinary least squared regression was performed for long bone length using the subjects’ known stature. Telkka et al. discovered distinct patterns, resulting in three subdivided age classes further divided between males and females – age classes included: juveniles less than 1 year old; between 1 and 9 years old; and between 10 and 15 years old. The youngest age class, comprised of juveniles under the age of one year, did not produce any linear relationships between long bone measurements and known stature, requiring each formula (for humerus, radius, ulna, femur, tibia, fibula for boys and girls) to be transformed using a logarithmic function. The transformation allowed Telkka et al. to perform a linear regression (see Table 6). Due to the logarithmic conversion, upper limb (humerus, radius, unla) formulae in the under 1 years old class require the use of a coefficient of 20, as calculated by Telkka et al., and the lower limb (femur, tibia, fibula) a formula coefficient of 40. The middle age class, made up of juveniles of 1 to 9 years old, produced linear relationships between long bone measurements and known stature for all long bones, except the femur. Similar to the younger age class, the femoral equation for 1 to 9 year olds could not be produced until a logarithmic transformation occurred (see Table 7). The eldest age class, for juveniles between 10 and 15 years old, only produced linear relationships between long bone measurements and stature, requiring no conversions (see Table 8). Errors for these estimates were higher than those in adult formulae with adult measurements. Errors were also higher for female estimations than male estimations, leading the authors to propose that linear regressions may not be useful for female subjects. Furthermore, they cautioned against relying on their own formulae in other populations, arguing that relying on a Finnish sample biased it toward the particularities of the Finnish population (Telkka, Palkama, & Virtama, 1962).

Table 6: Telkka et al. (1962) Formulae by bone for children under the age of 1 years old

Children under One Year of Age	BOYS	GIRLS
Femur	y=17.4+4.94x'±3.1	y=13.9+5.09x'±2.7
Tibia	y=17.3+5.95x'±3.8	y=14.2+6.14x'±2.7
Fibula	y=15.2+6.39x'±3.1	y=15.0+6.25x'±3.1
Humerus	y=7.5+7.88x'±2.5	y=6.6+7.90x'±3.1
Radius	y=2.5+10.56x'±3.1	y=7.5+9.81x'±3.8
Ulna	y=-1.1+10.14x'±3.3	y=0.49+9.91x'±4.0
	(2)x'=Vln(1+(x/V) V=20 for upper limbs V=40 for lower limbs	

Table 7: Telkka et al. (1962) Formulae by bone for children, 1-9 years old

Children Aged from One to Nine	BOYS	GIRLS
Femur	y=34.1+321log(1+(x/100))±4.1	y=31.7+329log(1+(x/100))±4.1
Tibia	y=38.4+3.43x±3.3	y=39.4+3.34x±5.2
Fibula	y=39.1+3.42x±3.1	y=40.1+3.35x±5.0
Humerus	y=28.0+4.41x±3.0	y=25.4+4.26x±4.9
Radius	y=23.0+6.38x±3.3	y=25.4+6.33x±3.5
Ulna	y=21.2+5.96x±3.1	y=24.6+5.74x±5.1

Table 8: Telkka et al. (1962) Formulae by bone for children, 10-15 years old

Children Aged from Ten to Fifteen	BOYS	GIRLS
Femur	y=10.0+7.37x±5.3	y=33.5+3.12x±5.3
Tibia	y=44.0+3.35x±	y=58.7+2.90x±6.8
Fibula	y=38.8+3.59x±6.9	y=44.5+3.42x±5.3

Children Aged from Ten to Fifteen	BOYS	GIRLS
Humerus	y=16.5+4.91x±4.2	y=36.9+4.11x±5.7
Radius	y=30.5+5.96x±4.6	y=35.3+5.85x±4.7
Ulna	y=26.7+5.73x±4.3	y=37.8+5.24x±4.8

Feldesman (1992) examined the ratio between femur length and stature in children between the ages of 8 and 18 years utilizing radiographic images from four child growth studies in the United States: (1) Tupman (1962) studied the trunk growth of 202 boys and girls between 7 and 16 years old. (2) Anderson (1963) collected femur lengths and statures once per year for 8 years from 50 girls and 50 boys. The sample was made up of 51 able-bodied children and 49 children suffering from poliomyelitis, commonly known as polio. Sixty percent of all male participants were measured from ages 8 to 10 years old and all were measured from ages 10 to 18. All female participants were measured from ages to 8 to 16, and half measured from ages 16 to 18. (3) Anderson (1964) reported the femur lengths of 67 males and 67 females. (4) Maresh (1970) conducted a long-term longitudinal study on the growth of 140 children – 75 males and 65 females. Mean limb bone lengths and mean statures were collected and reported. When describing the demographics of the child growth studies utilized, Feldesman referenced the historical tendency to rely on populations of European ancestry in the United States and suggested it is reasonable to assume the majority of the children in the growth studies were “white” (Feldsman, 1992, p. 450). Feldesman (1992) utilized total maximum femoral length and heights from these studies for 39 boys and 38 girls between the ages of 8 and 18 years old. After applying a correction to each dataset respective of its originating modality, Feldesman sought to compare femur ratios in children to femur ratios in adults. A previous study in adults revealed a femur length to stature ratio of 26.74%, where stature for an unknown adult could be solved for with the simple equation – stature= femur length x 3.74 (Feldesman, Kleckner, & Lundy, 1990). Feldesman (1992) found that this formula regularly underestimated juvenile stature by an average of 2.1 cm for juvenile males. The author then compared this to Trotter and Gleser's regression equation for white adult males (being applied at the time to juvenile remains) and discovered that it overestimated juvenile male stature by an average of 6.1 cm. Feldesman utilized the concept of the femur length/stature ratio from his previous study on adults (1990) as a basis for this study, creating a juvenile femur ratio based on a simple linear relationship between total maximum femur length and total body height. The equation requires the solving for stature by multiplying the femur length by 100 and dividing by a sex and age specific coefficient. The coefficient was created by dividing the mean of the sample population's femur length by the sample population's stature. The resulting predictive equations were categorized, first and foremost, by age, with annual age cohorts. Formulae were provided threefold: for male juveniles; for female juveniles; and for juveniles, regardless of sex. Age cohorts, regardless of sex, were found to be the most reliable overall ($p<0.001$).

Despite lacking the reliability of mixed sex cohorts, sexed age cohorts illustrated the need to always consider the importance of sex when predicting stature. Female subjects clearly entered a growth spurt between the ages of 8 and 12 years of age, contrasting with male subjects who experienced a similar growth spurt almost six years later, between the ages of 14 and 18 years old (Feldesman, 1992, p. 456). After the peak of these respective growth spurts, the femur length/stature ratio began to decline toward the adult ratio (see Tables 9 and 10).

Table 9: Feldesman (1992) Femur/stature ratio by age class and sex

Age (years)	Female femur/stature ratio	Male femur/stature ratio
8	26.26	25.98
9	26.63	26.36
10	26.91	26.75
11	27.17	27.01
12	27.35	27.29
13	27.3	27.29
14	27.21	27.56
15	27.11	27.54
16	27.06	27.46
17	26.97	27.36
18	26.95	27.24
Mean	26.99	27.1
SD	0.32	0.53

Table 10: Feldesman (1992) Age class means from a pooled sample

Age in years (number of specimens)	Femur/stature ratio
8.0 (4)	26.12
9.0 (4)	26.49
10.0 (9)	26.84
11.0 (10)	27.09
12.0 (9)	27.32
13.0 (8)	27.43
14.0 (8)	27.38
15.0 (8)	27.32
16.0 (8)	27.29
17.0 (6)	27.17
18.0 (4)	27.09
Mean of all classes (not weighted by sample size) = 27.05	Mean of all classes (weighted by sample size) = 27.13
SD = 0.41	SD = 0.33

Current models

Before delving into current models for estimating juvenile body mass and stature, it is important to note that most rely on the Denver Growth Study for their anthropometric information, thus requiring an understanding of the originating study itself. The Denver Growth Study was a longitudinal study of 334 juvenile subjects, conducted over the span of 40 years. Between 1927 and 1967, researchers from the Child Research Council followed juveniles from or around the time of the subject's birth through maturity, recording anthropometric, sociological, and clinical data to better understand human development (McCammon, 1970). Radiographs were created for subjects at 2, 4, 6, and 12 months of age, and again every 6 months after until the age of 17.5 years (Robbins Schug, Cowgill, Sciulli, & Blatt, 2013). One of the longest continuous studies with human subjects, the Denver Growth Study is said to specifically reflect the U.S. "middle class" (McCammon, 1970) and is comprised of related juveniles of mostly northern European ancestry (Sciulli & Blatt, 2008; Smith, 2007).

The current standard for juvenile stature and body mass predictions was published by Ruff (2007), who utilized the Denver Growth Study. Ruff made 690 total observations from the radiographic collections of 20 subjects, including 10 boys and 10 girls. Observations were made approximately every six months from birth to the age of 17, averaging 34.5 observation per subject. His regression model relied on age-based classes, arguing that rapid age-specific changes necessitate such division. Ruff proposed two separate body mass estimation models. For juveniles of unknown sex, body mass estimations were categorized by annual age cohorts, meaning Ruff's estimation models for 1 year olds should only be used on 1 years olds and so on. Ruff relied on femoral metaphyseal breadth and femoral head breadth to generate logarithmically transformed body mass estimation models for juveniles, aged 1 year to 17 years. Femoral metaphyseal breadth was used for juveniles from 1 to 12 years old. Femoral head breadth was used for juveniles 7 to 17 years old, creating an overlap between the two measurements across six age classes. Standard errors of estimation in these models are smallest (%SEEs 5-6%) between ages 2 and 7 years, and greatly increase from age 8 onward. Ruff argues the increased relationship between body mass and femoral breadth during the second year of growth is due to an increase in weight load from learning how to walk. Both measurements fail to provide precise body mass estimations after the age of 10 years, as all percent standard errors are above 13%. No equations for 15 to 17 year olds reach statistical significance.

To address the latter age classes (15-17 year olds), Ruff included sex based formulae based on pelvic bi-iliac breadth and long bone lengths (humerus, radius, femur, tibia). Estimations errors for the sex based bi-iliac breadth and long bone length formulae were 4-8% - smaller than estimations errors associated with the previous technique for the same age classes, making this method preferable for 15 to 17 year olds if the material is available.

Ruff based stature estimation models on humeral length, radial length, combined humeral and radial lengths, femoral length, tibial length, and combined femoral and tibial lengths. For both humeral and femoral lengths, diaphyseal length was considered for ages 1 to 12 years old and total length considered for ages 11 to 17 years old.

Estimations relied on the combined bone lengths provided similar or lower %SEEs than multiple regression equations for multiple long bones. Femoral and tibial lengths produced the lowest %SEEs, as the bones contribute directly to stature, and their combined lengths provided the lowest %SEEs of all the study's stature estimation formulae. All lower limb %SEEs were 1.5-2.4% and all upper limb %SEEs were 1.9-2.9% (Ruff, 2007).

The same year, Smith (2007) analyzed stature in juvenile remains also utilizing radiographs from the Denver Growth Study. Smith relied on the longitudinal growth study to create mixed-sex and single-sex regression formulae based on the six long bones – humerus, radius, ulna, tibia, femur, fibula – and the combined femur and tibia length. Measurements were taken from 31 boys and 36 girls, 3-10 years old. Children older than 10 years old were excluded because girls experience an early growth spurt associated with puberty around this age. Given the intertwined genealogies of many of the Denver Growth Study's subjects, relatives of the same sex were also excluded. Smith generated three sets of regression equations – one to be used when the sex of remains are unknown and two for when sex is known. Smith's regression equations illustrated a statistically significant relationship between bone length and stature, particularly when utilizing the femur and tibia together (Smith, 2007). The combination of femoral and tibial length for the mixed sex regression equations produced the lowest standard error (1.97) and a similar R^2 (0.98) to the same equations for tibia and fibula. Interestingly, the femur, which is normally considered the most reliable estimator of stature in juveniles and adults, had a marginally lower R^2 of 0.97, and a standard error higher (2.46) than the other long bones previously mentioned (see Table 11).

Table 11: Smith (2007) regression equations for children of unknown sex

	Equation	SE (cm)	R^2	n	Mean(x) (mm)
Humerus	0.4658(x)+27.053	3	0.96	762	200.74
Radius	0.6229(x)+27.500	3.16	0.95	762	149.4
Ulna	0.5898(x)+23.742	2.91	0.96	761	164.12
Femur	0.2928(x)+36.923	2.46	0.97	758	285.68
Tibia	0.3519(x)+38.614	2.24	0.98	762	232.85
Fibula	0.3620(x)+37.273	2.24	0.98	762	230.11

Smith then created sex based regressions (see Tables 12 and 13). For girls, the combined femoral and tibial lengths provided the greatest R^2 (0.98) and the lowest standard error (2.10). However, the equations for boys departed from this trend. The fibula produced the smallest standard error (1.53). It also provided the greatest R^2 (0.99) of all the regression formulae, across sex based and non-sex based equations. That noted, all of Smith's equations performed similarly and were statistically significant.

Table 12: Smith (2007) regression equations for girls, by long bone

	Equation	SE (cm)	R^2	n	Mean(x) (mm)
Humerus	0.4668(x)+27.006	3.4	0.94	423	201.12
Radius	0.6269(x)+27.747	3.23	0.95	423	148.59
Ulna	0.5906(x)+24.276	2.94	0.96	423	163.59
Femur	0.2984(x)+35.609	2.26	0.98	421	285.66
Tibia	0.3475(x)+39.641	2.57	0.97	423	233.83
Fibula	0.3600(x)+37.768	2.68	0.97	423	230.92

Table 13: Smith (2007) regression equations for boys, by long bone

	Equation	SE (cm)	R^2	n	Mean(x) (mm)
Humerus	0.4644(x)+27.151	2.41	0.97	339	200.27
Radius	0.6218(x)+26.623	2.75	0.96	339	150.41
Ulna	0.5906(x)+22.777	2.66	0.96	338	164.79
Femur	0.2860(x)+38.536	2.63	0.96	337	285.71
Tibia	0.3581(x)+37.213	1.73	0.98	339	231.62

	Equation	SE (cm)	R^2	n	Mean(x) (mm)
Fibula	0.3645(x)+36.643	1.53	0.99	339	229.1

Robbins, Scuilli, and Blatt (2010) proposed a new means of predicting body mass. Previously, the only means of predicting body mass included distal femur metaphysis in those under 12 and femoral head breadth in older juveniles (Ruff, 2007). Robbins et al. (2010) offer another option - midshaft femur cross sectional geometry. The study again used the longitudinal Denver Growth Study for data on 20 well-fed, healthy juveniles from 2 months to 17 years old. Relying on the femur lengths, external diaphyseal diameter, and cortical bone thicknesses reported by Ruff (2003), Robbins et al. calculated the torsional rigidity (*J*) from the cortical thickness minus the medullary diameter multiplied by a cylindrical coefficient of $\frac{\pi}{32}$ (Robbins, Sciulli, & Blatt, 2010; Ruff, 2003) (see Table 14). The resulting torsional rigidity was then transformed via a logarithmic function with recorded weights to produce body mass regression formulae (see Table 15). The model was compared to Ruff (2007) using an independent 186 juvenile sample from Franklin County, Ohio. Body mass estimations derived from both studies did not differ in a statistically significant manner when used for the independent sample population (Robbins, Sciulli, & Blatt, 2010; Ruff, 2007). This was a particularly interesting result considering the Franklin sample population is comprised of one quarter African American subjects, whereas the Denver Growth Study exclusively includes juveniles of European heritage. Despite cross sectional geometry being approximately as accurate as femoral head measurements in estimating body mass, it provides more options in forensic cases where femoral heads may be damaged or have no known association with an individual, as in the case of multiple graves (Robbins, Sciulli, & Blatt, 2010).

Table 14: Robbins, Sciulli, & Blatt (2010) Formula for torsional rigidity

$$J = (T4 - M4)x \frac{\pi}{32}$$

Where J is torsional rigidity;
T is cortical thickness;
M is medullary diameter

Table 15: Robbins, Sciulli, & Blatt (2010) Formulae for predicting body mass (kg) from femoral torsional rigidity (J)

Age (years)	Body Mass	BMI	Intercept	Slope	F	P	SEE	%SEE
0	4.52	15	3.8	0.003	3.454	0.086	0.27	6.0
1	9.05	17	7.1	0.002	15.40	0.001	0.61	6.7
2	11.59	16	8.1	0.002	16.96	0.001	0.68	5.9
3	13.57	15	10.5	0.001	8.44	0.009	0.92	6.8
4	15.45	15	11.4	0.001	13.45	0.002	1.00	6.5
5	17.25	15	12.8	0.001	14.94	0.001	1.06	6.1
6	19.25	15	14.2	0.001	15.83	0.001	1.23	6.4
7	21.72	15	15.8	0.001	15.10	0.001	1.38	6.4
8	24.25	15	16.0	0.001	19.85	<0.0001	1.75	7.2
9	28.70	16	17.1	0.001	7.430	0.014	4.11	14.3
10	31.87	17	16.3	0.001	8.81	0.009	5.05	15.84
11	35.87	17	18.4	0.001	8.70	0.009	6.06	16.89
12	39.53	18	19.2	0.001	12.24	0.003	6.48	16.39
13	44.44	18	21.1	0.001	16.89	0.001	7.00	15.75
14	49.89	19	30.4	0.001	8.505	0.010	7.29	14.61
15	53,92	20	36.6	0.001	9.463	0.007	6.41	11.88
16	59.16	20	45.8	0.000	3.815	0.067	8.13	13.74
17	59.63	21	46.2	0.000	6.244	0.023	7.84	12.76

Finally, one of the most recent studies of body mass and stature estimation questions the necessity for age categorization (Robbins Schug, Cowgill, Sciulli, & Blatt, 2013). Typical regression models, such as Ruff's, rely on Ordinary Least Squares Regression (OLS) formulae. Age class regression formulae, such as those from Ruff (2007), require an age estimate at the time of death. It has been argued that these were necessary to account for the rapid development in juveniles (Ruff, 2007). Robbins Schug et al. (2013)

argue that age estimations, even in juveniles, are not always accurate thus introducing an additional error to body mass, and stature estimation models. For this study, the authors did away with age classes, simply providing a series of regression formulae for larger age classes. Robbins Schug et al. collected measurements from the femoral distal metaphyseal breadth, femoral midshaft geometry, and femoral head diameter from the Denver Growth Study. The authors then regressed the information, in conjunction with the associated dependent variable (height or weight). For estimating stature from femur length, a single formula was created for juvenile remains aged between 0.5 and 11.5 years old based on femur length; for body mass, two formulas for those aged between 0.5 and 12.5 years old based on breadth of the distal femoral metaphysis and the diameter of the femoral head; for body mass, one formula for those aged 7 to 17.5 years old based on the diameter of the femoral head.

Robbins Schug et al. then tested the validity of their formulae against measurements from in the Franklin County collection and an assembled global sample of juvenile skeletal remains in comparison to the field standard (Ruff, 2007). The Franklin County collection includes 186 juveniles collected between 1990 and 1991. It is composed of one quarter African American subjects, and three quarters white subjects. Unlike the Denver Growth Study, the Franklin County collection includes a variety of socioeconomic classes in the United States, in addition to cases associated with trauma and chronic illness. Trauma cases included six instances where measurements were procured within two hours of death and verified against medical records. Biographical details, such as dates of birth and death, sex, ancestry, weight, and height were utilized in conjunction with cadaver measurements. The second sample population contained archaeological subjects from California, Kentucky, Alaska, Bosnia, Portugal, Nubia, and South Africa. Archaeological subjects were as from as far back as 300 BP and as recent as from the twentieth century. Robbins Schug et al. found their formulae for stature without regard to age and Ruff's (2007) age class formulae for stature estimated the stature of the independent sample populations equally well. This suggests that when age estimations are not discrete, the use of a formulae without specific regard to age at time of death may be the best practice. The study also found body mass particularly difficult to estimate from Robbin Schug et al.'s formulae and Ruff's (2007) formulae, suggesting that body mass has a more complicated relationship with femoral development than stature does (Robbins Schug, Cowgill, Sciulli, & Blatt, 2013; Ruff, 2007).

Evaluations of current models

In response to Ruff's (2007) study, Sciulli and Blatt (2008) tested Ruff's formulae against an independent sample of 186 subjects from the Franklin County Collection. Body mass was calculated based on femoral head breadth or femoral distal metaphyseal breadth, using formulae from Ruff (2007). Stature estimations were based on femur, tibia, radius, and humerus lengths input into the formulae provided by Ruff (2007). Although Sciulli and Blatt's sample population was noticeably different, the authors found the existing formulae to be "relatively" accurate (Sciulli & Blatt, 2008). Body mass estimations from 1 to 13 year olds were equally accurate for the African American subjects from the Franklin County Collection as they were for the white subjects, where accuracy was calculated as the difference between the observed body mass of a subject and the estimated body mass, in kilograms. When the authors controlled for age, sex, and ancestry, accuracies for Ruff's (2007) formulae ranged from 3.5 to 6.5 cm (Sciulli & Blatt, 2008).

Cardoso (2009) revisited Feldesman's (1992) femur length/stature ratio method and tested it against the long bone regressive models of Telkka et al. (1962) and Smith (2007) utilizing the remains of nine identified immature skeletons from the Bocage Museum in Lisbon, Portugal. The subjects were seven males and two females, all contemporary in origin, between the ages of 1 and 14 years old. Cardoso's measurements specifically relied on known cadaver measurements, unlike the studies Cardoso was testing. Telkka et al. (1962) and Feldesman (1992) studies relied on radiographs. All three methods were tested on a single sample. Cardoso found that not only was the femur length/stature ratio the least reliable, but all three methods consistently fell short of their mark. When Cardoso utilized the femur/stature ratio for specimen 735-A, a 13-year-old female, the formulae underestimated her stature by as much as 28.3 cm (Cardoso, 2009). In fact, the stature of the sample population consistently underestimated by formulae largely relying on lower limbs. Cardoso concluded the study by noting that his skeletal sample consisted of individuals raised in less than ideal conditions and noting that juvenile stature models are not universal – possibly leaving room for future study of upper limbs.

Non-femur related models for juveniles

Kimura (1992) estimated juvenile stature based on second metacarpal measurements in Japanese children of various locales from Tokyo to Sapporo to Kagoshima. The second metacarpal was chosen in part because there is little sexual dimorphism in it and sex and age are often not known in forensic contexts. Radiographs of the right hands of 552 boys and 542 girls, between the ages of 6 and 20 years, were examined. Length and width measurements were taken of the second metacarpal. Length provided the most accurate measurements between the two, but combined, length and width produced the most accurate results. Stature could be estimated from the second metacarpal with a standard error of 4.19 cm in skeletally immature children ignoring sex (Kimura, 1992).

The relationships described in the study between stature and the second metacarpal are interesting to consider but must be appropriately contextualized – Telkka et al. (1962) and Cardoso (2009) argue against broad utilization of formulae derived from specific populations as the formulae are not truly universal.

Factors Influencing the Accuracy of Height and Weight Data

Diurnal variation

Humans are at their tallest for the first two hours after rising from laying down for an extended period – generally speaking, this means in the morning upon waking from an evening's rest. Gravity and individual weight cause the vertebral column to become compressed during waking hours when an individual is not laying down. This phenomenon has been well documented since the 1700's (Wasse, 1724). However, diurnal height variation or intraindividual variation is commonly unaccounted for when stature is measured, including when measured at doctor's offices, thus causing biases in the reliability of studies utilizing these measurements.

Siklar, Sanli, Dallar, and Tanyer (2005) evaluated how diurnal decrease may have affected the height measurements of 478 children between the ages of 3 and 15 years old – 235 boys and 243 girls. The mean age of the subject population was 9.9 years old. Children were measured twice per day – once in the morning between 0900-1000 hours and again between 1500-1600 hours. All subjects were measured barefoot. Stature was measured using a Harpenden stadiometer with the subject's head in the Frankfort plane. A single trained observer took all measurements to avoid interobserver error. To further avoid bias, the observer did not review the initial measurements recorded when measuring the subject for the second time. The order of the participants measured by the researcher was randomized. Upon review of the collected data, Siklar et al. found a significant variability between the initial and subsequent measurements. Of the subjects, 32 experienced no height variation during the five hours between measurements; 98 subjects experienced an increase in height; 349 subjects experienced a decrease in height. It was suggested that those who experienced a gain in stature may have rested prior to measurements allowing for vertebral compression to be alleviated. Siklar et al. reported no significant differences between age groups or sexes. Stature increased in some subjects as much as +1.8 cm and decreased as much as -2.7 cm. The mean difference was -0.47 ± 0.05 cm. Siklar et al. point out that although -0.47 cm may not to the naked eye appear an important difference in height measurement, it is enough in a medical situation to alter a patient's diagnosis and treatment plan. A child may be labeled as "short" based on a biased observed growth velocity and provided with unnecessary medical intervention (Siklar, Sanli, Dallar, & Tanyer, 2005).

Krishan and Vij (2007) also studied diurnal variation of stature, though their study focused on the repeated measurements of the same four individuals over a 56-day period in order to specifically emphasize the intraindividual component of the diurnal variation phenomenon. The study followed two adult males (Subject A, 59.1 years, and Subject B, 31.8 years), an adult female (Subject C, 25.1 years), and a child (Subject D, 9.0 years) over the course of 56 days with each subject measured four times a day, each day. Each subject was measured by the same trained anthropologist, again to avoid interobserver error, and all measurements were taken independent of previous measurements. The observer reportedly measured all four subjects reportedly within 30 seconds of them rising in the morning at approximately 0600 hours. Subjects were measured again at 0800 hours, 1800 hours, and 2200 hours, just before retiring to bed. Measurements were taken utilizing an anthropometer via the Weiner and Lourie technique and rounded to the nearest 0.1 cm. At the end of the trial period, Krishan and Vij analyzed stature variation per individual. The mean daytime stature loss for Subject A was 2.81 ± 0.29 cm; Subject B was 2.55 ± 0.30 cm; Subject C was 2.06 ± 0.27 cm; and Subject D was 1.95 ± 0.28 cm. Stature loss appeared to occur most during the first two hours after rising. Stature loss continued throughout the day but at a substantially slowed rate. Krishan and Vij suggested that Subjects A and B experienced the greatest stature loss for several reasons, including they were the tallest of the subjects and they engaged in more physically strenuous activities during a day than Subjects C and D (Krishan & Vij, 2007).

Self-reporting

In studying juvenile body mass and stature during life, it is not uncommon for studies, both medical and anthropological, to rely on self-reported height and weight data (e.g. the U.S. Centers for Disease Control have utilized self-reported data in the past to determine the number of American children suffering from obesity). However, it has been repeatedly shown that self-reported height and weight in both juveniles and adults is unreliable. This is also important to consider as height and weight for comparisons in forensic cases may feature self-reported data. For example, it is not uncommon for height and weight to be incorrect on a driver's license, driving permit, or other state issued identification card – all forms of identification on which a forensic investigation may rely. Furthermore, when younger children are involved and a parent or guardian may be reporting height and weight, it is also important to consider they are also subject to reporting errors.

Instances of overweightness in adolescents tripled in the United States between the 1970s and 1990s – from 5% to 14% of the juvenile population (Berner, McManus, Galuska, Lowry, & Weschsler, 2003). To better understand this trend, the CDC affixed questions regarding height and weight to their already existing Youth Risk Behavior Surveillance System (YRBSS) in 1999. Berner et al. (2003) investigated the validity and reliability of self-reported height, weight, and BMI in youth relying on the CDC's

YRBSS for their framework. The authors relied on a convenience sample drawn from 61 schools across 20 states and the District of Columbia. The schools were dispersed across all 21 areas with 48% of the schools in urban settings, 39% suburban, and 13% rural. The subject population included students enrolled in grades nine through twelve and totaled 4,619 individuals. A subsample across 31 of the original 61 schools was selected to be measured by a trained observer in addition to subjects taking the self-administered survey. The subject subpopulation, after two schools were eliminated due to probable systemic error, totaled 2,032. The study's sex distribution closely mirrored those of the United States (i.e. the sample population was 52.9% female and 47.1% male, compared to the national trend of 49.9% female and 51.0% male). Racial and ethnic demographics were similarly skewed – the sample population was more than 40% black or African American, more than double the national distribution, whereas white and Hispanic subjects made smaller percentages of the sample (43.2% and 7.4%, respectively) compared to national averages (64.8% and 13.3%, respectively). All subjects completed a self-administered questionnaire featuring approximately 100 multiple choice questions. The survey included information on demographics, overall health, and asked subjects to report their height in inches without shoes, and their weight in pounds without shoes. All measurements were recorded for subjects without hats, shoes, removable hair accessories, and external clothing, such as coats or jackets. Height was measured to the nearest 1 cm and weight to the nearest 0.1 kg, with the scale balanced out to zero before each use.

The entire process of completing the questionnaire and measuring the subsample population was repeated two weeks later. Berner et al. (2003) compared the self-reported data from the first data collection event to the self-reported data from the second data collection event and discovered a strong correlation – in the first iteration of the survey, 14.5% of the subject provided BMIs classifying them as “at risk for overweight” and 13.2% for “overweight”; the second iteration, it was 14.8% and 13.0%. Using linear regression, the authors found no significant subgroup differences in the self-reported data. However, the measured data revealed discrepancies – based on measured values, 21.4% of the subject population was “at risk for overweight” and 26% were “overweight”. Furthermore, Berner et al. found a variety of subgroup differences in the measured data. When sex and grade were controlled for, white subjects were more likely to over-report their height ($p=0.001$). With sex and race or ethnicity controlled for, the higher the subject’s school level, the more likely they were to over-report their height ($p<0.001$) and underreport their weight ($p=0.002$). With grade and race or ethnicity controlled for, female subjects were more likely to underreport their weight and subsequently, their BMI, as it was calculated by researchers based on the information the subject provided ($p=0.001$). When provided with categories to describe one’s BMI – “neither”, “at risk of overweight”, and “overweight” – the self-reported data were in moderate agreement with the measured with 71.2% of subjects being classified in the same regardless of dataset used. When relying on two categories – “overweight” and “not overweight” – the data had a much stronger agreement of 87.7%. Berner et al.’s analysis indicates that although self-reported height, weight, and BMI calculations are highly reliable insofar as subjects consistently provided similar information during both data collection events. However, the validity, or confidence that can be invested in the information provided, is questionable as subjects consistently provided reliable information but the information was inaccurate (Berner, McManus, Galuska, Lowry, & Weschsler, 2003).

Himes, Hannan, Wall, and Neumark-Szainer (2005) further explored the validity of self-reported metrics, particularly in association with personal characteristics. Himes et al. relied on the data from Project E.A.T (Eating Among Teens), a study focusing on collecting data regarding adolescent nutrition and obesity in association with socioeconomic status. The sample population utilized by Himes et al. included 3,797 subjects, from ages 12 to 18 years old – 1936 boys and 1861 girls – living in the Minneapolis and St. Paul metropolitan areas of Minnesota and attending one of the collaborating 31 local schools. Subjects were asked to answer questions regarding height and weight in a personal interview. The same or following day, trained staff measured subjects without their shoes. Body measurements could not be collected for 10.6% of the sample population due to absences. Of subjects with body measurements, self-reported height and weight were missing for 5% and 4%, respectively. Subjects with incomplete data tended to be younger (mean of age of subjects with incomplete data 14.5 years versus mean of overall population 14.9 years) and shorter (160.1 cm versus 164.2 cm). Subjects were categorized according race or ethnicity – white, African American, Hispanic, Asian (largely originating from the South East via Laos, Vietnam and Cambodia), and “other”. The “other” racial category was comprised of subjects of “mixed ethnicity” 48%, American Indian heritage 45%, and Native Hawaiian or Pacific Islander heritage 7%. Subjects were also categorized according to their familial socioeconomic status (SES), based on a 1-5 scale system factoring in parental education, family eligibility for public assistance, eligibility for free or reduced price school lunch programs, and parental employment.

Himes et al. noticed a few significant patterns within and between subgroups. When examining sex differences in self-reported data and measured data, the authors discovered males overestimated their stature by an average of 1.2 cm and females by 2.4 cm. Weight was underestimated by both sexes as well by an average of 1.6 kg in males and 3.5 kg in females. This led to BMI underestimation by males by an average of 2.2 kg/m^2 and by 2.5 kg/m^2 by females. Males also increased their overestimation of stature with age while both sexes decreased their underestimation of weight with age. When controlling for SES and age, Himes et al. found no significant racial differences among girls but did note that Asian male subjects overestimated their stature less than males of other races and ethnicities but underestimated their weight more. In examining SES, males from all classes tended to overestimate their height but males from the highest (assigned to classes 4 and 5 on the assessment scale) over-reported their stature the most – those from class 1 over-reported stature by an average of 1 cm; class 2 by 0.7 cm; class 3 by 0.9 cm; class 4 by 1.5 cm; and class 5 by 2.0 cm. White, Hispanic, and African American females higher on the SES scale underestimated their weight more than girls of the same race or ethnicity on the lower end of the scale. However, Asian female subjects of high SES underestimated their weight the least. Like in Berner et al.'s (2003) study, the authors found that self-reported data consistently underreported instances of "at risk for overweight" and "overweight" ($p<0.001$). Self-reported data indicated that 26.6% of males and 24.3% of females were “at risk of overweight”; 11.0% of males and 8.9% of females were “overweight”. These figures are a dramatic departure from the measured data – 32.3% of males and 33.0% of females were “at risk of overweight”; 14.8% of males and 11.8% of females were “overweight”. All of this indicated a high overall validity of self-reported height and weight via a Pearson correlation of 0.80 to 0.96. However, beyond averages, self-reported height and weight data appear to have strong correlations to personal characteristics (Himes, Hannan, Wall, & Neumark-Sztainer, 2005).

Elgar, Roberts, Tudor-Smith, and Moore (2005) utilized the Health Behavior in School-Aged Children (HBSC) survey to evaluate the validity of self-reported height and weight from 418 subjects in Wales. Data from the 1998 HBSC Welsh sample was utilized. The dataset was assembled in cooperation with 51 nationally distributed schools. At time the survey was administered in 1998, half of the participating school were randomly chosen to collect height and weight measurement for year 11 students, in addition to administering the associated survey. Twenty-one of those schools agreed to perform the measurements. The subject population included 418 year 11 students – 190 boys, 225 girls, and 3 of unknown gender. The mean age was 16.30 years with a range of 15 – 17 years. No private or special needs schools were included in the 51 participating schools, and homeless or incarcerated subjects were not included. Trained staff at each school measured height and weight using a height chart and weight scale, respectively. Subjects kept their clothes, including outer layers like coats, and shoes on for these measurements. Elgar et al. adapted the information in this dataset to analyze BMI in age and sex-appropriate calculations, rounding to 0.1 m (height) and 0.1 kg (weight). There was a high degree of correlation between self-reported and measured height, weight, and BMI. The authors found that was no difference in self-reported and measured height in boys or girls. However, girls underreported their weight, $p<0.001$. BMIs based on self-reported data were lower than BMIs based on measured data in boys and girls, both $p=0.03$. Based on self-reported data, 13.9% of the subject population could be classified as “overweight” and 2.8% “obese”. Yet, measured data identified 18.7% of the subject population as “overweight” and 4.4% obese, indicating an underestimation of overweightness of 4.8%. Elgar et al. correlated BMI with answers from the original survey regarding body perception and found a strong direct relationship between negative body perception and instances of underreporting weight. This occurrence suggests that although self-reported height and weight have a high correlation to measured height and weight, self-reported data is inherently more bias prone and should be utilized carefully (Elgar, Roberts, Tudor-Smith, & Moore, 2005).

Complicating socioeconomic factors

Juvenile stature and body mass calculations are also affected by the development of the skeleton itself during life. Genetics are a key determining factor in the potential body mass and stature of a juvenile. However, a variety of social factors place limitations on that potential.

The importance of parental SES accounted for differences in child height in another European study. Rona, Swan, and Altman (1978) authored a longitudinal study involving

9,815 children from England and Scotland – 7,601 and 2,214 respectively – aged 5 through 11 years old, hailing from 22 randomly stratified areas in England and six randomly stratified areas in Scotland. Local nurses at either health centers or schools took measurements and provided parents with questionnaires inquiring about father's employment and social class, parents' height, sibship size (e.g. the number of siblings raised together and sharing parental resources), child's birthweight, and mother's age at the birth of the study subject. The questionnaire, supported by stature measurements, indicated a strong correlation between a father's SES, sibship size, and child stature. The higher the father's SES and steadier his employment, the more likely boy children in the family would be in the higher percentile for height. The more older siblings a child had, regardless of parental SES, the more likely the child would be in the lower percentiles for height (Rona, Swan, & Altman, 1978). These conclusions suggest that stature is not influenced just by genetics but also social pressures acting on the juvenile body, such as access to adequate nutrition.

Similarly, research conducted in Poland found a positive correlation between the height of offspring and marital distance (e.g. the geographical distance between the birthplaces of parents) suggesting that humans benefit from heterosis or "hybrid vigor" (Koziel, Danel, & Zareba, 2011). Heterosis posits that populations benefit from breeding between two independent lines, increasing the occurrences of positive characteristics. The authors argue that the result of "tallness" in offspring is a positive impact on the characteristic height due to conditions resulting in reduced metabolic costs allowing for additional growth.

Koziel et al. recorded the heights of 2,675 boys and 2,603 girls, between ages 6 and 18 years old, yearly between 1994 and 1999, to examine how martial distance impacted the development of children. Their results showed that greater marital distance was associated with greater height. Their study acknowledged other known factors that might have biased their results; for example, high marital distance can also be correlated with higher socioeconomic status (SES) – people who can travel far from home generally have financial resources that those restricted to their hometowns do not (Koziel, Danel, & Zareba, 2011).

A more recent study brought a biocultural lens to the topic of stature calculations by comparing two archaeological populations of Giecz, Poland and Trino Vercellese, Italy to modern populations, the Makushi of British Guyana and the Riberinhos of Brazil, to understand stature as a result of selective environmental pressures (Vercelloti, et al., 2014). These two archaeological populations were chosen for their completeness and the plethora of data surrounding socio-economic variation. Not only did they measure stature in and across these populations but the authors also considered factors such as stress indicators including dental hypoplasia and cribi orbitalis. Skeletal populations were measured utilizing one of a derivation of the anatomical method. Living populations were measured for stature, sitting height, and subischial leg length. Their findings suggested stature is not the sole result of stress limiting growth or genetics. Rather stature development is related to stress within populations, especially those that are highly socially stratified (Vercelloti, et al., 2014).

Conclusions

Although the most accurate means of estimating juvenile body mass and stature has been speculated on by the anthropological community – largely through the comparison of different skeletal elements and comparisons to adult studies, formulae, and populations – there is not yet a definitive estimation method. A plethora of factors complicate approaches to this subject. Juvenile development is affected not just by genetics, but also social factors ranging from parental socioeconomic status to marital distance. The reporting of juvenile height and weight is biased through studies relying on self-reporting or not accounting for diurnal stature variation. Utilizing these estimation studies as framework, the following study creates new stature and body mass estimation formulae, carefully considering the merits of age class cohorts, and sex based regression formulae.

METHODS

The overarching goal was to create new body mass and stature formulae for modern American juveniles to more accurately represent children of today. This study collected five unique femoral measurements, as well as height, weight, sex, race, and ethnicity information from juvenile subjects to generate regression formulae for juvenile body mass and stature. The five femoral measurements were chosen to compare to height or weight based on their inclusion in previous studies on the topic or speculated biomechanical importance. Other metrics, such as age, sex, race, and ethnicity were also chosen due to their potential impacts on the development of juvenile skeletons.

The study was accomplished through collaboration with the radiology department of Children's Mercy Hospital in Kansas City, Missouri. This study followed protocols approved by the Institutional Review Boards of Humboldt State University (approval #16-092) and Children's Mercy Hospital (#16110798). All radiographic reports and materials were provided by and only accessed at Children's Mercy Hospital in Kansas City, Missouri, from December 2016 – January 2017. The original database created for this study was created with radiographic images, computed tomographic images, and scanograms from Children's Mercy Hospital. Images were generated between January 1, 2008 and October 1, 2016. The database started with over 11,000 radiographic descriptions. Duplicates were removed from the final subject population, along with subjects whose medical history may have altered their height, weight, and/or femoral development. This culling resulted in a database of over 4,000 subjects. Qualitative information was collected in the form of sex, and racial and ethnic identification within existing hospital records. Quantitative information collected included the age, height, weight of subjects and five measurements of the femur from scanograms and radiographic reports.

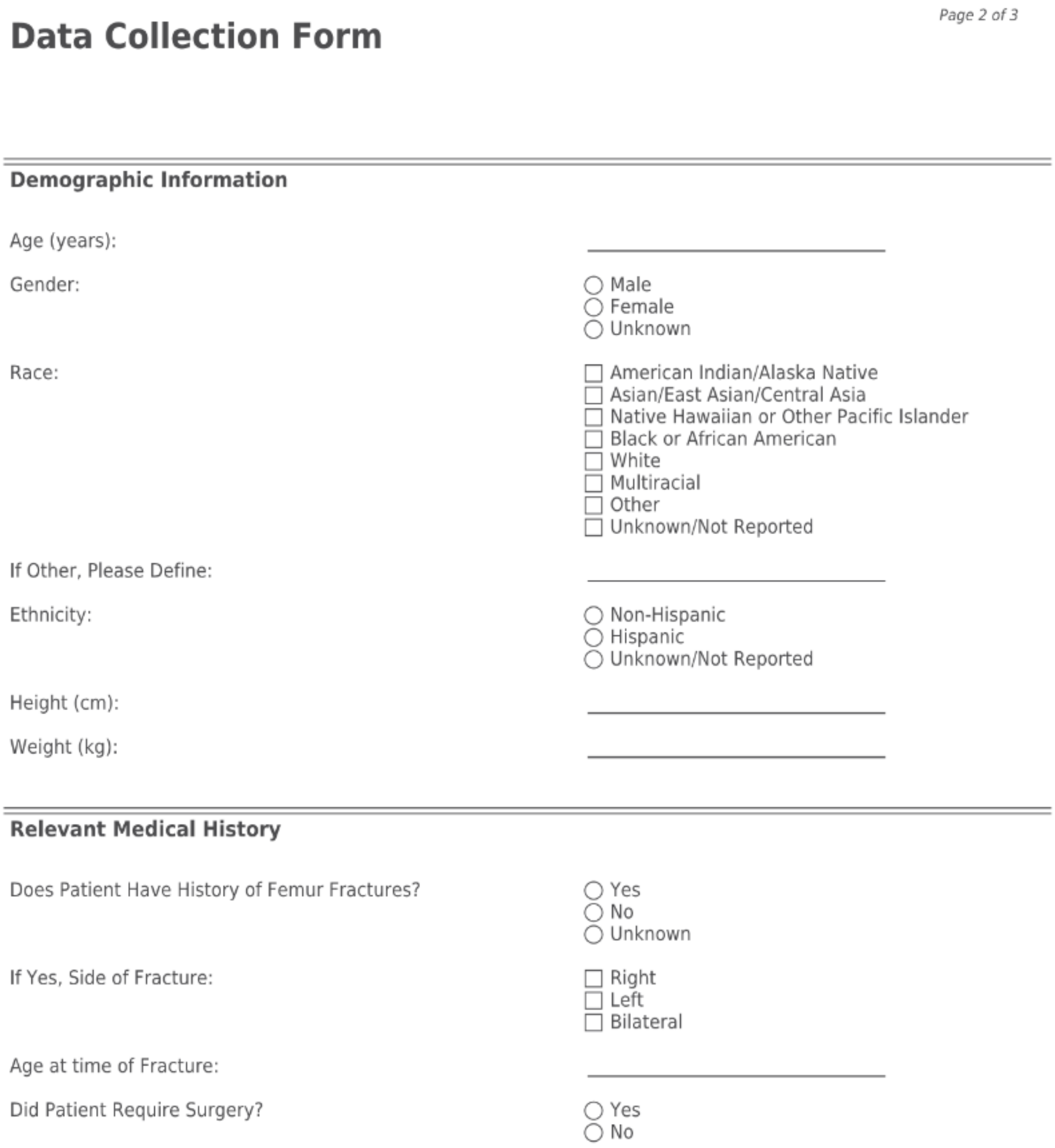
Radiographs are created when concentrated beams of x-ray photons are projected on to a subject with a metal film behind them. The photons pass through the individual's soft tissues but are absorbed by the hard tissues, such as bone. The photons that passed through the soft tissue are absorbed by the metallic film, resulting in opaqueness on the film. Where the photons were absorbed by hard tissues, transparent shapes are made. This process allows for internal examination. For this study, the radiographs utilized were taken anterior to posterior, meaning the photons were concentrated on the front of the body and the resulting image is in the posterior view. Study subjects were supine at the time of creation, except in rare cases, where weight bearing was required for the orientation by medical staff.

Subject Population

This study was based on images collected as part of emergency or routine clinical examinations at Children's Mercy Hospital between January 1, 2008 and October 1, 2016. All images were from subjects between 12 months to 17 years of age. Radiographs (e.g. x-rays), scanograms (i.e. a computed tomography imaging technique utilized to specifically measure the discrepancies in limb length), and general computed tomography (CT) images of the femur in the anteroposterior view were utilized. Where bilateral images of a subject’s femora were available, the right femur was measured. Subjects with localized anomalies affecting the femur, and illnesses and/or injuries suspected to affect stature and/or body mass development were excluded from the study (see full list of exclusions in Appendix A). When an image was demeaned anything outside of “normal” by a radiologist in the image description, the image was excluded from the study. Where images for a given subject were available for multiple occasions while in an age class (e.g. a subject with multiple images while 9 years old), only one image was used to represent that subject for that age year. The image utilized was chosen for clarity and ability to provide as much information as possible. However, where multiple images were available for the same subject across age cohorts, one image *per* age cohort was used. Therefore, a single subject’s information could contribute to multiple age groups but that information could only be utilized once per applicable age group. The age, sex, height, and weight at the time of the image being created were recorded by researchers when possible. At time of subject intake, medical staff was not always able to record weight and/or height. When weight and/or height at time of image creation were not available, weight and/or height recorded within a week (7 days) of image creation was utilized by researchers. If multiple weights and/or heights were reported by medical staff at within a week of image creation, the weight and/or height closest to the day and time of image creation was recorded by researchers. If more than one weight and/or height was reported, the weight and/or height that was listed as “medically calculated” and displayed at the top of the subject’s medical chart was chosen. Weights and/or heights listed as “medically calculated” are utilized by medical staff for medicinal dosage calculations and were therefore deemed the most reliable. Data on race and ethnicity were also collected. Race and ethnicity was orally reported to hospital staff at time of intake and included in subject profiles. Of the approximately 4,000 images that met the criteria for inclusion of the study, information on race and ethnicity was gathered from 676 individuals. The race and ethnicity of subjects in the sample population were requested in separate questions and recorded as separate metrics within their medical charts and by the research staff.

Information Collection and REDCap

Children's Mercy Hospital provided access to three separate databases to collect and correlate all necessary data for this study. An Excel workbook was initially used to store descriptions of all available radiographs, computed tomography images, and scanograms meeting this study's research criteria. Created by hospital staff, the Excel workbook included the subject's medical record number (MRN), last and first name, sex, age, the organization responsible for the image's creation (inside and outside of Children's Mercy Hospital), the modality (x-ray/CT), the date and time of the exam, the exam accession number (the unique identification utilized to retrieve the image in the hospital's digital network), an exam description, a report text, and a field for search terms to be added by researchers. Each exam description detailed a clinical impression by hospital staff regarding the image. For example, a radiologist would indicate if the imaged femur appeared "normal" or was affected in some way, such as fractured. To decide if it was reasonable to include a given image in this study, the principal investigator and an assistant read each exam description for over 11,000 images and applied a “search term” for each (see Appendix A for encountered descriptors resulting in exclusion). Images with femurs determined to be clinically “abnormal” were excluded from this study. Once this was completed, a browser based research database, known as Research Electronic Data Capture, or REDCap, was created by hospital staff to capture desired information (see Figure 1).



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Data Collection Form

Demographic Information

Age (years): ______________

Gender:
○ Male
○ Female
○ Unknown

Race:
☐ American Indian/Alaska Native
☐ Asian/East Asian/Central Asia
☐ Native Hawaiian or Other Pacific Islander
☐ Black or African American
☐ White
☐ Multiracial
☐ Other
☐ Unknown/Not Reported

If Other, Please Define: ______________

Ethnicity:
○ Non-Hispanic
○ Hispanic
○ Unknown/Not Reported

Height (cm): ______________

Weight (kg): ______________

Relevant Medical History

Does Patient Have History of Femur Fractures?
○ Yes
○ No
○ Unknown

If Yes, Side of Fracture:
☐ Right
☐ Left
☐ Bilateral

Age at time of Fracture: ______________

Did Patient Require Surgery?
○ Yes
○ No

Figure 1: REDCap database collection form

The final de-identified subject population was uploaded to REDCap. All data to be collected were tracked in this database for the rest of the study. Utilizing the study identification number in REDCap, subject’s MRNs were pulled from the Excel workbook and then used to access the subject’s medical information in another software program, PowerChart Pro. PowerChart Pro included subjects’ age, sex, height, and weight at time of visit, race, and ethnicity as reported at time of intake. PowerChart Pro also allowed researchers to determine if any medical conditions affecting normal femur, stature, and body mass development were present, requiring the removal of a subject from the study such scoliosis. When this occurred, the subject and their associated data were deleted from the REDCap database. If a subject had a previous history of femur fractures, it was noted in REDCap alongside demographic information.

Once the appropriate demographic information was recorded in REDCap from PowerChart Pro, the Excel workbook was accessed again. Using the same subject’s study identification number, the associated image accession number was copied and pasted into IntelePACs, a software for digital radiographic analysis (see Figure 2). IntelePACs searched its internal databases based on the accession number and displayed the associated radiograph, CT, or scanogram. Researchers then employed the program’s measuring tool, codified as a tape measure, to measure the subject’s femur. Like the demographic information from PowerChart Pro, the measurements from IntelePACs were recorded in the REDCap database. Once a single subject’s data “profile” was completed, researchers marked it as such and the database updated itself accordingly, allowing researchers to work independently without recording the information for any single subject more than once.

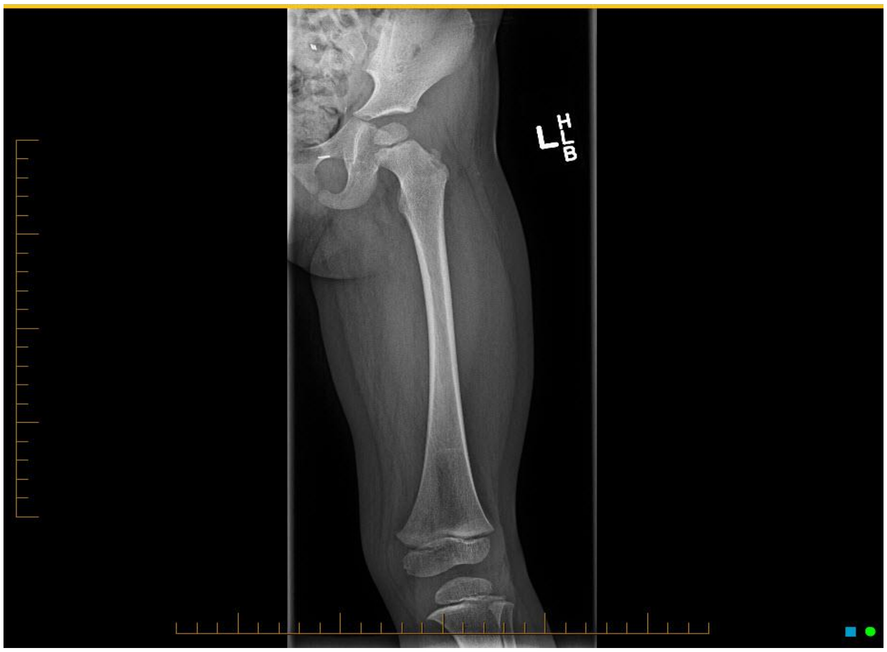


Figure 2: Radiograph of juvenile femur, posterior view, as seen in IntelePACs

The principal investigator and research assistant subdivided the sample population, each becoming responsible for approximately half of the age classes. The principal investigator was responsible for collecting data on subjects 12 months old, and subjects between the ages of 11 and 17 years of age, attempting to generate an age class in similar size and quality for each year. The research assistant was responsible for subjects between the ages of 24 months and 10 years old.

Femur Measurements

To estimate stature, the total maximum femoral length was measured to include epiphyses (e.g. growth plates) – it was measured from the most distal point of the femoral medial condyle to the most proximal point of the femoral head (see Figure 3, line labeled 1). The diaphyseal (inter-metaphyseal) length was also measured. Diaphyseal length was defined as the maximum length between proximal and distal ends of a femur, parallel to the diaphysis (e.g. the shaft of a long bone). Measurements began after the pectineal line and continued distally, ending superior to the supracondylar ridge. Thus, the diaphyseal length measurement did not include epiphyses and effectively measured the rounded upper shaft to the flattened lower shaft of the juvenile femur (see Figure 3, line labeled 4).

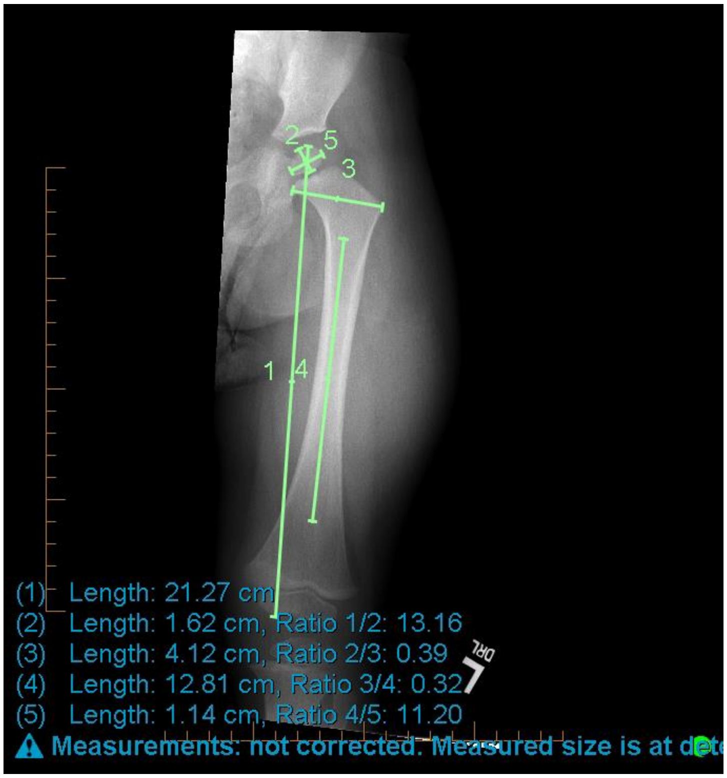


Figure 3: Radiograph with femoral measurements imposed over it
1. Total maximum length; 2. Superoinferior head breadth; 3. Mediolateral neck breadth;
4. Diaphyseal length; 5. Mediolateral head breadth

To estimate body mass, the maximum superoinferior femoral head breadth, mediolateral femoral head breadth, and the maximum mediolateral femoral neck breadth were measured. Maximum superoinferior femoral head breadth was measured perpendicular to the head-neck axis (see Figure 3, line labeled 2). The maximum mediolateral femoral head breadth was measured between the most medial and most lateral points of the femoral head (see Figure 3, line labeled 5). Maximum mediolateral femoral neck breadth was measured between the most medially and laterally projecting points on the metaphyseal surface almost perpendicular to the long axis of the femoral shaft (see Figure 3, line labeled 3).

Total maximum length, and superoinferior head breadth were both included in this study due to their inclusion in previous studies – the measurements from previous works were logical starting points (Ruff, 2007; Smith, 2007; Robbins Schug, Cowgill, Sciulli, & Blatt, 2013). Total maximum length has been a reliable predictor of height in the past (Ruff, 2007; Smith, 2007). It has also been incorporated into body mass estimations through torsional rigidity calculations (Robbins, Sciulli, & Blatt, 2010; Robbins Schug, Cowgill, Sciulli, & Blatt, 2013). Superoinferior head breadth has also been used after logarithmic transformation to estimate body mass (Ruff, 2007).

Diaphyseal length and mediolateral head breadth were included after a consultation with radiology staff at Mercy Children's Hospital. The hope was that including diaphyseal length may account for some of the information lost due radiographs split over two films in taller/older subjects where total maximum length could not be recorded. Mediolateral head breadth was included to accompany the superoinferior head breadth measurement – reasoning that the biomechanics affecting one are likely to affect the other.

Mediolateral neck breadth measurements do not appear to have been included in other juvenile body mass, or stature studies. It seemed logical to include the femoral neck as it bears the brunt of gravitational forces applied to an individual's body mass.

The distal metaphyseal breadth of the femur was excluded from this study. This is a departure from current literature that relies on the measurement to predict body mass (Ruff, 2007; Robbins Schug, Cowgill, Sciulli, & Blatt, 2013). It was excluded due to concerns regarding the quality of the measurement in the radiographs, wherein shadows are common due to other nearby skeletal material (i.e. the patella).

Measurements were obtained electronically using the software program, IntelePACs. Where scanograms were available, measurements completed by researchers were forgone by those already calculated by computer. Scanograms rely on computed tomography to measure the discrepancies in limb length and therefore included a series of measurements calculated based on comparisons between left and right legs. However, scanograms were few and far between. Of the 676 images analyzed, less than five were scanograms. Measurements were completed in IntelePACs utilizing its internal measuring tool. Once opened, the tool allowed for the principal investigator and research assistant to click on the point of origin on the image and drag the cursor across the image, generating a line. The line could be moved and its length adjusted. Once it was created, IntelePACs calculated the distance. No variation correction was applied to images as one is applied at time of digitization. This is of note since previous studies relying on radiographs, such as Feldesman (1992) had to apply corrections for magnification. It is also important to note that all measurements came from living, "wet" bone in this study. As previously noted by Rollet (1888), living bone in adults is longer than the stereotypical dry bones anthropologists work with – he noted a loss of 2 mm during the drying process. However, a similar annotation regarding the loss children suffer has not been indicated so all data derived from the radiographs have not be transformed to accommodate for loss of length during the drying process.

Statistical Analysis

Before analysis began, non-age based regressions were decided on as the primary outcome. As previously noted by Robbins Schug et al. (2013), age cannot always be effectively estimated in juvenile remains. Thus, all primary body mass and stature estimation formulae resulting from this study would be most useful if they were made regardless of age class. However, later secondary analyses were considered for comparison purposes.

All data were exported from the REDCap database to an Excel workbook. Within Excel, an ordinary least squares (OLS) regression and one-way analysis of variance (ANOVA) was performed to determine the relationship between the independent variables (the femoral measurements) and dependent variables (weight, and height) and create regression equations for predicting stature and body mass.

Data were graphed in a scatter plot within Excel. Stature and its predictor variables (total maximum femoral length and femoral diaphyseal length) appeared to have a linear relationship, and thus data were not manipulated prior to regression analysis. However, the relationship between weight and its predictor variables (mediolateral femoral head breadth, superoinferior femoral head breadth, and mediolateral femoral neck breadth) were exponential. Thus, prior to OLS regression, weight was log-transformed via the natural logarithm function in Excel. The OLS regression and one-way ANOVA were then completed utilizing the femoral measurement and the calculated natural logarithm of the weight. In all instances, statistical significance was set at $p<0.05$.

RESULTS

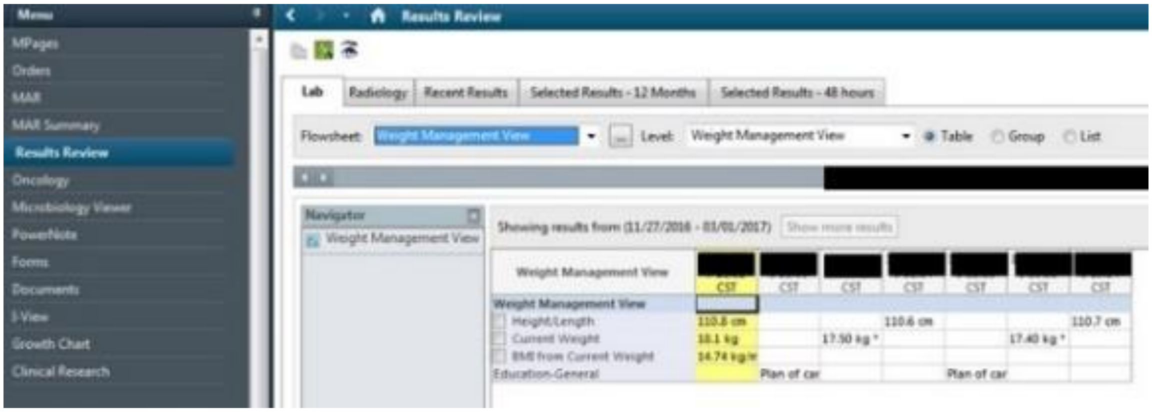
Limitations and Potential Biases of this Study

This study was limited and potentially biased by a number of factors. All race and ethnicity data were orally communicated to hospital staff (likely by parents/guardians) upon subject check-in. The biases introduced here were twofold. Self-reported data goes through some level of personal editing, depending on the situation, therefore limiting its accuracy. This was compounded by the fact that all responses were orally communicated to a secondary party who then had to report it in a digital chart with limited options. Questions regarding race and ethnicity also require mentioning the limiting, problematic nature of these labels. Historically, race has been treated as a biological fact. However, more and more anthropologists are moving toward understanding race as a social construct based on selected phenotypic traits.

The ability to collect measurements, particularly of the maximum length of the femur, was highly limited in older juveniles. Once an individual is over a certain height, the femur, and other long bones, are split over two radiographic films. This study found that children over 120 cm tall were more likely to require their limb imaging split over two films. In the sample population, children were likely to reach this height between 7 and 8 years of age. This resulted in fewer observations for older individuals. For example, there were 18 observations for total maximum length for 7 year olds but only 10 observations for the same measurement for 8 year olds. When split over two films, it was only practical to measure the length of the femur when a clear landmark was visible in both films, essentially making it impossible to accurately measure the length of the femur. Separate films could have been "stitched" together; however, this would have required a substantial time investment from a radiograph technician. The resulting lesser amount of complete observations from older juveniles (> ca. age 8 years) biases the non-age-based analyses performed within this study.

Further, images of femora with no fractures were generally less common for preteens to teenagers (10 to 17 years of age) than for children under the age of 10. Based on the radiographic descriptions made available for this study, younger children, especially those under the age of 3 years old, were more likely to have their limbs imaged when no fractures were present. This could be due to the fact that young children may not be able to effectively communicate their pains and are thus imaged for exploratory purposes, or because older children are more likely to be admitted with fractures to the femur due to athletic-related injuries.

Height and weight measurements were also not consistently available. Medical charts were more likely to include the weight of a subject than the height. Outside of regular check-ups, height was not necessarily an important metric for care. However, weight was recorded with some degree of regularity as it is utilized to calculate medicinal dosages (see Figure 4). Height was not recorded regularly in subjects under the age of 4 years. Both weight and height may have also been excluded if the admittance occurred as the result of an emergency, such as an automobile collision. In such instances, immediate action would have taken precedence over recordation.



Flowsheet: Weight Management View Level: Weight Management View ● Table ○ Group ○ List

[redacted]

Showing results from (11/27/2016 - 03/01/2017)

Weight Management View	[redacted] CST	[redacted] CST	[redacted] CST	[redacted] CST	[redacted] CST	[redacted] CST	[redacted] CST
Weight Management View							
☐ Height/Length	110.8 cm			110.6 cm			110.7 cm
☐ Current Weight	18.1 kg		17.50 kg *			17.40 kg *	
☐ BMI from Current Weight	14.74 kg/m						
Education-General		Plan of car			Plan of car		

Figure 4: Medical chart in PowerChart Pro program showing recordation of height and weight for a subject

Finally, all results are subject to human error. Recorded measurements clearly outside the realm of physical possibility were considered a typo and were either corrected when original intent could be reasonably deciphered or excluded when it could not. However, serious outliers were included, such as children suffering from obesity and extreme obesity. Numerous American children fall outside the recommended body mass by age group set forth by medical organizations. Including these subjects, in some cases, significantly altered results. However, excluding them would result in models that were not indicative of a modern population.

Human error also reasonably includes interobserver error. Due to the time constraints of this study, each measurement could not reasonably be recorded by both researchers nor could a sizable number for each subgroup (e.g. age group, sex, etc.) be documented by both in order to calculate the technical error of measurement (TEM) (Lewis, 1999). Thus attempts to account for interobserver error were made through collaboration between researchers. Gordon and Bradtmiller (1992) concluded that practice with specific measurements was more important than longtime experience when reducing measurement error (Gordon & Bradtmiller, 1992). Researchers discussed the measurements at length and practiced them in the IntelePACs program before beginning documentation. Additionally, Figure 18 was included in the REDCap database where measurements were entered for visual reference to minimize drift where possible (Kouchi, Mochimaru, Tsuzuki, & Yokoi, 1999).

Demographics

This study includes information from 676 subjects. Of these subjects, 365 identified or were identified by a parent or guardian as male (53% of total population), 309 as female (46%), and 2 as “unknown” (<1%); this is similar yet skewed from the US national average of 49.2% male and 50.8% female.

Seven distinct racial identities were recorded by hospital and research staff: American Indian or Alaskan Native; Asian; Native Hawaiian or Other Pacific Islander; Black or African American; White; Multiracial; and Other. An eighth option of Unknown or Not Reported was also included. The 676 subjects provided answers that skewed slightly away from national trends. Less than sixty percent of subjects identified as White, only slightly less than the 61.6% of Americans who identify as “White alone, not Hispanic or Latino”. Those identifying as Black or African American made up 19% of the subject population compared to 13.3% of the nation’s population (Quick Facts: United States, 2015). The third largest racial group was composed of those who either declined to identify themselves or whose race was unknown (13.1%). The remaining 6.3% largely identified as multiracial (see Table 16).

Since this study relied on a single hospital database, it is possible the sample population is subject to regional population trends, not just national trends. Given Children's Mercy Hospital's proximity to both Kansas and Missouri, population demographics of both states were also considered (Quick Facts: United States, 2015). The sample population, overall, most closely resembled the national population of the United States, if only slightly. The sample population was closer to national trends in three identities – black or African American (19.38% of sample population versus 13.30% of national population), Native Hawaiian or other Pacific Islander (0.44% versus 0.20%), and white (56.66% versus 77.10%). The sample population more closely resembled Missouri in its number of Native American, and Asian subjects – 0.30% of sample population versus 0.60% of Missouri's population, and 1.78% versus 2.00%, respectively. Finally, the number of multiracial subjects most closely represents the same population in Kansas – 5.62% versus 2.90% (see Table 16).

Table 16: Racial and ethnic breakdown of sample population compared to the population of the United States, Kansas, and Missouri

Race & Ethnicity	% of Subject Population	% of U.S. National Population	% of Kansas Population	% of Missouri Population
American Indian or Alaskan Native	0.30% (n=2)	1.20%	1.20%	0.60%
Asian	1.78% (n=12)	5.60%	2.90%	2.00%
Black or African American	19.38% (n=131)	13.30%	6.30%	11.80%
Native Hawaiian or Other Pacific Islander	0.44% (n=3)	0.20%	0.10%	0.10%
White	56.66% (n=383)	77.10%	86.70%	83.30%
Multiracial	5.62% (n=38)	2.60%	2.90%	2.20%
Other	2.81% (n=19)	N/A	N/A	N/A
Unknown or Not reported	13.71% (n=89)	N/A	N/A	N/A
Hispanic or Latino	12.77% (n=84)	17.60%	11.60%	4.10%
Non-Hispanic	0.30% (n=2)	61.60%	76.40%	79.80%
Declined to indicate if Hispanic or non-Hispanic	86.93% (n=572)	N/A	N/A	N/A

In a separate question, subjects were asked to label their ethnicity (Hispanic or Latino, non-Hispanic, Unknown or Not Reported). The majority of subjects declined to answer the ethnicity question – of the 658 responses, 84 (12.76%) self-identified as Hispanic, and only 2 (<1%) self-identified as non-Hispanic, meaning 572 chose to decline identifying either way.

The age of the subject cohort skewed young. Of the 676 subjects, 152 were between 12 and 23 months old, the largest age cohort by a factor of 5. All other age cohorts (2 years of age to 17 years of age) included anywhere between 30 and 37 members. If grouped into age classes for every five years, the subject population can be subdivided in three. Those 12 months old to 5 years old make up almost 8% more of the sample population than the national population (40.83% versus 32.70%). In contrast, 6 year olds through 11 year olds make up 5% less of the sample population the national population (28.99% versus 33.38%). The final age class comprised of 12 year olds through 17 year olds almost exactly mirrors national trends (Child Population: Number of Children (in millions) Ages 0–17 in the United States by age, 1950–2015 and Projected 2016–2050, 2015) (see Table 17).

Table 17: Age breakdown of sample population in comparison to population of the United States

Age (Years)		% of Subject Population n=676	% of U.S. Juvenile National Population N=73,700,000
1	22.49% (n=152)	40.83% (n=276)	32.70% (n=24,100,000)
2	4.44% (n=30)		
3	4.73% (n=32)		
4	4.59% (n=31)		
5	4.59% (n=31)		
6	4.44% (n=30)	28.99% (n=196)	33.38% (n=24,600,000)
7	4.59% (n=31)		
8	5.03% (n=34)		
9	5.03% (n=34)		
10	5.18% (n=35)		
11	4.73% (n=32)		
12	4.59% (n=31)	30.18% (n=204)	31.39% (n=25,000,000)
13	4.59% (n=31)		
14	4.73% (n=32)		
15	5.47% (n=37)		
16	5.33% (n=36)		
17	5.47% (n=37)		

Characteristics of Subject Population

This study relied on the diverse clientele of Children’s Mercy Hospital to build a sample population reflective of modern American juveniles. Not only is this sample population more diverse racially and ethnically from the Denver Growth Study and the Franklin County Collection, it is also physically more diverse. The physical diversity in femoral lengths in association with height (see Table 19), and femoral head and neck breadths in association with weight (see Table 18) is achieved via a cross sectional approach.

Table 18: Descriptive statistics (mean, standard deviation, minimum-maximum range) for body mass measurements

		SI Head	Breadth			ML	Head	Breadth		ML	Neck	Breadth
Age (years)	n	Mean (cm)	SD	Range (cm)	n	Mean (cm)	SD	Range (cm)	n	Mean (cm)	SD	Range (cm)
1	107	0.750	0.15	0.33-1.20	105	1.08	0.18	0.60-1.47	109	3.05	0.30	2.28-3.87
2	40	1.020	0.203	0.48-1.62	40	1.58	0.273	0.99-2.09	41	3.81	0.399	2.90-4.55
3	22	1.276	0.221	1.03-2.08	22	2.114	0.351	1.11-2.71	22	4.585	0.329	3.70-5.08
4	27	1.301	0.176	0.88-1.61	27	2.399	0.287	1.51-2.93	27	4.977	0.425	4.13-5.96
5	28	1.418	0.361	0.88-2.86	28	2.555	0.35	1.63-3.39	27	5.116	0.409	4.28-6.11
6	23	1.524	0.15	1.23-1.82	23	3.109	0.302	2.60-3.70	23	5.805	0.487	5.03-6.94
7	26	1.607	0.31	1.14-2.57	24	3.166	0.577	1.30-4.03	24	5.818	0.408	5.09-6.49
8	29	1.737	0.196	1.37-2.22	29	3.603	0.348	2.95-4.24	29	6.339	0.593	4.84-7.48
9	27	1.722	0.268	1.13-2.20	27	4.002	0.752	3.14-6.86	28	6.671	0.551	5.55-7.75
10	30	1.789	0.227	1.25-2.28	30	4.056	0.33	3.44-4.62	30	6.762	0.907	3.62-8.08
11	29	1.885	0.261	1.41-2.47	29	4.2	0.491	3.16-5.73	29	7.194	0.71	5.10-8.13
12	29	1.868	0.203	1.34-2.21	28	4.544	0.252	4.13-5.12	29	7.756	0.581	6.72-8.91
13	24	1.952	0.258	1.40-2.51	23	5.062	0.464	4.29-6.14	23	6.861	0.855	4.61-8.32
14	18	1.936	0.291	1.27-2.48	19	4.802	0.328	4.27-5.44	21	7.272	0.724	6.11-8.52
15	26	2.084	0.322	1.49-2.71	26	5.009	0.392	4.28-5.92	27	8.124	0.891	5.98-9.61
16	29	2.038	0.291	1.41-2.40	30	5.071	0.756	3.75-8.30	31	7.804	1.02	5.14-10.06
17	22	1.934	0.387	1.11-2.54	24	4.95	0.503	4.28-5.93	25	7.922	1.13	5.67-10.28

Table 19: Descriptive statistics (mean, standard deviation, minimum-maximum range) for stature measurements

			Total	Max. Length		Diaphyseal		Length
Age (years)	n	Mean (cm)	SD	Range (cm)	n	Mean (cm)	SD	Range (cm)
1	21	16.63	0.84	14.88-18.11	21	8.71	0.770	6.70-9.92
2	23	21.57	1.97	16.25-24.09	24	11.52	1.530	7.65-13.72
3	18	25.07	1.863	22.39-29.73	18	12.769	1.278	10.81-15.50
4	22	27.86	1.546	25.14-31.68	22	14.301	0.995	12.85-17.24
5	23	30.59	2.203	26.53-36.10	24	16.148	1.570	13.57-19.52
6	18	33.03	1.182	30.44-35.17	21	17.7	1.478	14.48-21.72
7	18	34.68	2.449	30.81-40.07	21	18.201	2.4	13.66-22.78
8	10	38.16	2.904	34.70-46.03	22	20.768	1.861	17.36-24.32
9	7	41	2.452	36.42-45.01	25	22.226	1.64	18.34-25.02
10	8	39.94	2.064	36.34-42.76	21	22.134	2.136	18.54-27.38
11	8	41.69	2.451	38.08-44.95	18	22.691	2.268	18.51-27.99
12	7	49.36	2.541	43.56-51.76	20	27.166	2.166	23.30-30.40
13	1	47.13	0	47.13	1	28.76	0	28.76
14	4	46.02	4.938	41.30-54.17	4	28.143	2.026	26.48-31.48
15	2	47.71	4.035	43.67-51.74	4	29.488	2.207	25.94-31.39
16	1	60.68	0	60.68	2	35.6	11.82	33.78-37.42
17	2	53.12	0.655	52.46-53.77	3	30.733	2.089	27.85-32.73

Results

<u>Body mass</u>

Upon analyzing the superoinferior head breadth, the mediolateral head breadth, and the mediolateral neck breadth of the femur in conjunction with a subject's weight, an exponential pattern was revealed (Tables 20, 21, and 22). All three measurements produced highly statistically significant relationships (all p values <0.001). However, mediolateral head breadth produced the highest R^2 (0.91) and ANOVA F (5278.79), suggesting a closer correspondence to body mass (see Figure 6). Superoinferior head breadth (see Figure 5) performed only slightly better than mediolateral neck breadth (see Figure 7).

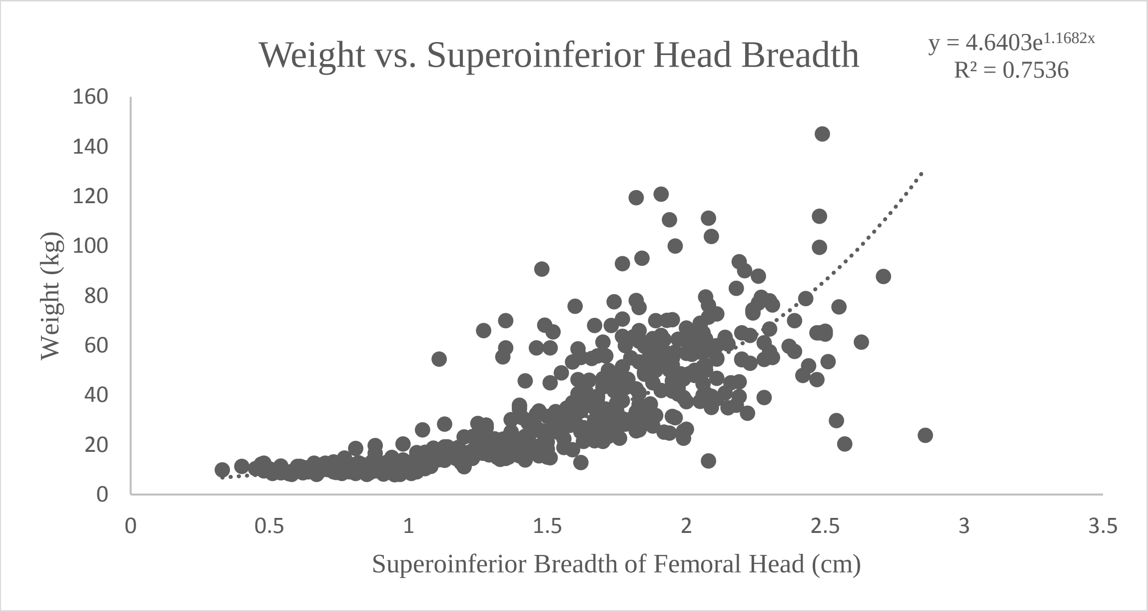


Figure 5: R^2=0.75, ANOVA F=1632.96, p< 0.001, n=536

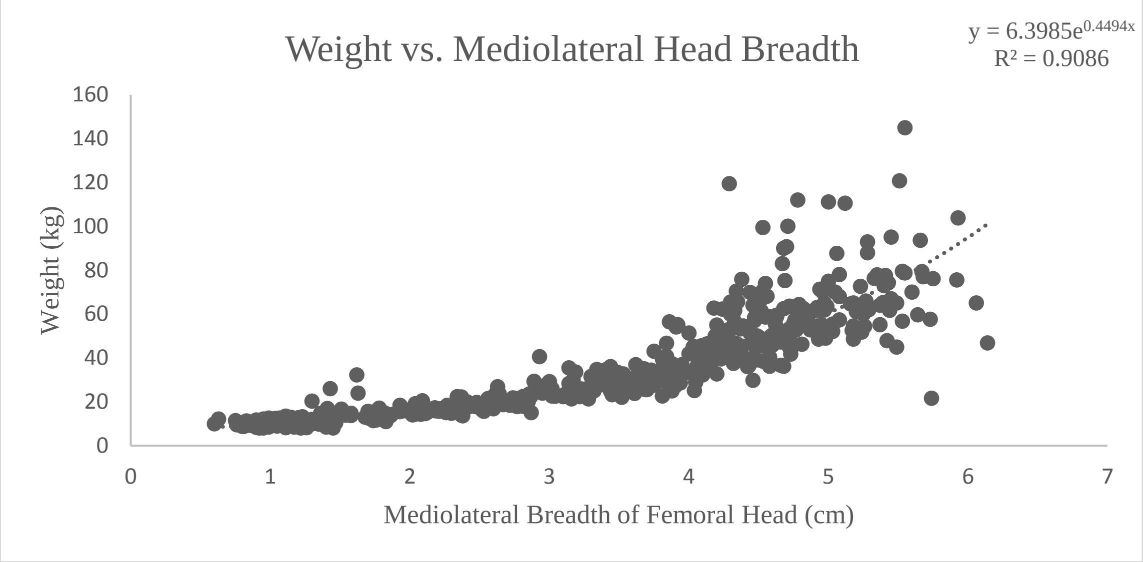


Figure 6: R^2=0.91, ANOVA F=5278.79, p<0.001, n=533

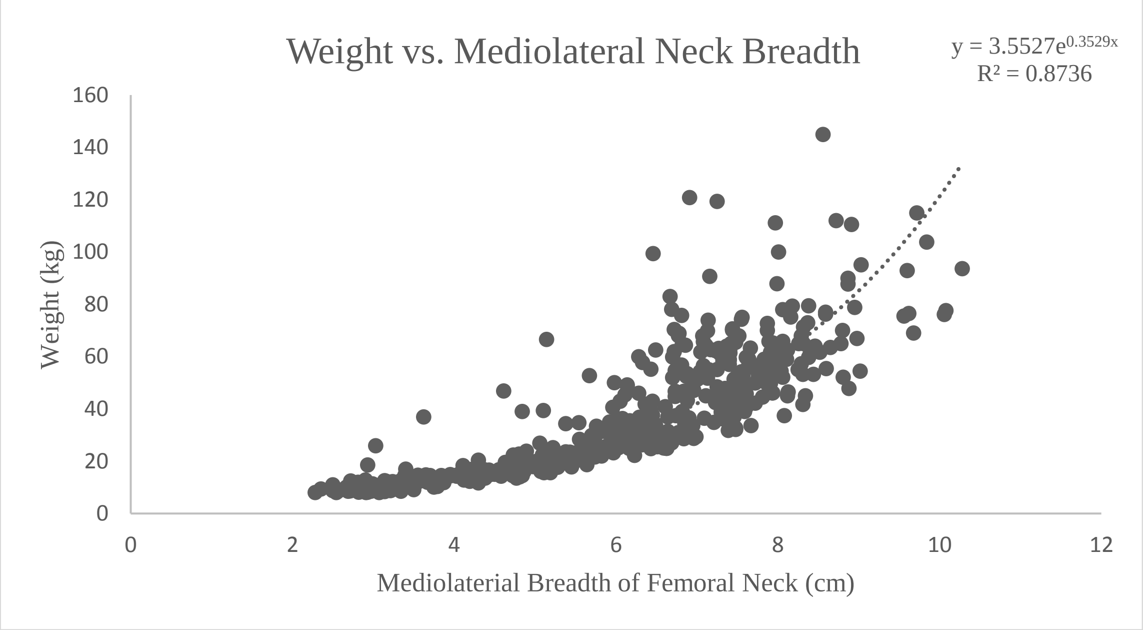


Figure 7: R^2=0.72, ANOVA F=1365.44, p<0.001, n=545

Table 20: Regression formulae for body mass as a variable of superoinferior femoral head breadth where $y=be^{mx}$

			Superoinferior	Head	Breadth		
Age (years)	n	Slope	Intercept	R^2	P	Standard Error	ANOVA F
1 -17	536	1.168	4.640	0.754	<0.001	0.351	1632.958
1	107	0.087	9.577	0.007	0.395	0.159	0.731
2	40	0.290	9.928	0.168	0.009	0.134	7.668
3	22	-0.029	16.712	0.002	0.830	0.135	0.047
4	27	0.426	10.418	0.137	0.057	0.196	3.978
5	28	0.187	15.148	0.175	0.027	0.152	5.510
6	23	0.347	14.807	0.103	0.136	0.161	2.404
7	26	0.162	19.484	0.095	0.127	0.162	2.506
8	29	0.483	13.821	0.169	0.027	0.218	5.502
9	27	0.631	11.744	0.363	<0.001	0.233	13.963
10	30	0.482	16.244	0.175	0.021	0.246	5.955
11	29	0.175	15.894	0.260	0.733	0.715	0.118
12	29	0.233	33.683	0.031	0.363	0.275	0.857
13	24	0.269	32.103	0.098	0.136	0.220	2.393
14	28	0.315	33.818	0.161	0.099	0.222	3.068
15	26	0.141	49.577	0.035	0.363	0.250	0.860
16	29	0.297	36.121	0.105	0.087	0.262	3.165
17	21	0.229	44.424	0.203	0.040	0.177	4.839

Table 21: Regression formulae for body mass as a variable of mediolateral femoral head breadth where $y=be^{mx}$

			Mediolateral	Head	Breadth		
Age (years)	n	Slope	Intercept	R^2	P	Standard Error	ANOVA F
1 -17	536	0.418	6.979	0.835	<0.001	0.860	1365.437
1	109	0.151	6.451	0.086	0.002	0.151	10.082
2	41	0.198	6.304	0.305	<0.001	0.122	17.145
3	21	0.139	8.501	0.124	0.109	0.128	2.823
4	27	0.322	3.660	0.454	<0.001	0.156	20.798
5	27	0.253	5.432	0.397	<0.001	0.132	16.472
6	23	0.221	6.972	0.438	<0.001	0.180	16.385
7	24	0.316	3.985	0.613	<0.001	0.107	34.897
8	29	0.154	12.181	0.157	0.033	0.220	5.024
9	28	0.404	2.347	0.649	<0.001	0.170	48.129
10	30	0.116	17.608	0.161	0.028	0.248	5.382
11	29	0.214	8.688	0.360	<0.001	0.210	15.157
12	29	0.213	10.010	0.210	0.012	0.248	7.175
13	23	0.139	20.915	0.275	0.010	0.202	7.956
14	21	0.085	33.238	0.082	0.208	0.217	1.700
15	27	0.074	36.545	0.075	0.166	0.241	2.038
16	31	0.074	36.856	0.077	0.600	0.895	0.281
17	25	0.168	17.865	0.503	<0.001	0.196	23.272

Table 22: Regression formulae for body mass as a variable of mediolateral femoral neck breadth where $y=be^{mx}$

			Mediolateral	Neck	Breadth		
Age (years)	n	Slope	Intercept	R^2	P	Standard Error	ANOVA F
1 -17	545	0.353	3.553	0.874	<0.001	12.669	5278.787
1	105	0.520	9.614	0.004	0.521	0.149	0.414
2	40	0.300	8.320	0.323	<0.001	0.122	18.164
3	22	0.194	10.686	0.273	0.013	0.117	7.510
4	27	0.380	7.283	0.290	0.004	0.178	10.196
5	28	0.157	13.226	0.116	0.076	0.158	3.405
6	23	0.319	9.318	0.352	0.003	0.137	11.382
7	24	0.201	13.320	0.469	<0.001	0.129	19.439
8	29	0.453	6.179	0.468	<0.001	0.174	23.743
9	27	0.608	3.526	0.664	<0.001	0.162	45.353
10	30	0.480	5.504	0.366	<0.001	0.215	16.168
11	29	0.214	8.688	0.426	<0.001	0.199	20.008
12	28	0.213	10.010	0.177	0.026	0.258	5.595
13	23	0.080	36.922	0.033	0.409	0.210	0.711
14	19	0.086	40.860	0.016	0.610	0.237	0.269
15	26	0.248	19.190	0.158	0.044	0.234	4.515
16	30	0.074	36.856	0.058	0.202	0.275	1.710
17	24	0.332	12.760	0.450	<0.001	0.193	17.981

Stature

Stature was analyzed as a function of total maximum femoral length or diaphyseal length and height. Both were found to have highly linear, highly statistically significant relationships (p values <0.001) (see Tables 23, and 24). Total maximum femoral length produced the higher R^2 (0.94) and ANOVA F (3094.86), compared to diaphyseal length (R^2=0.88, ANOVA F=1961.01) (see Figure 9). This indicates a stronger bond between stature and total maximum femoral length (see Figure 8).

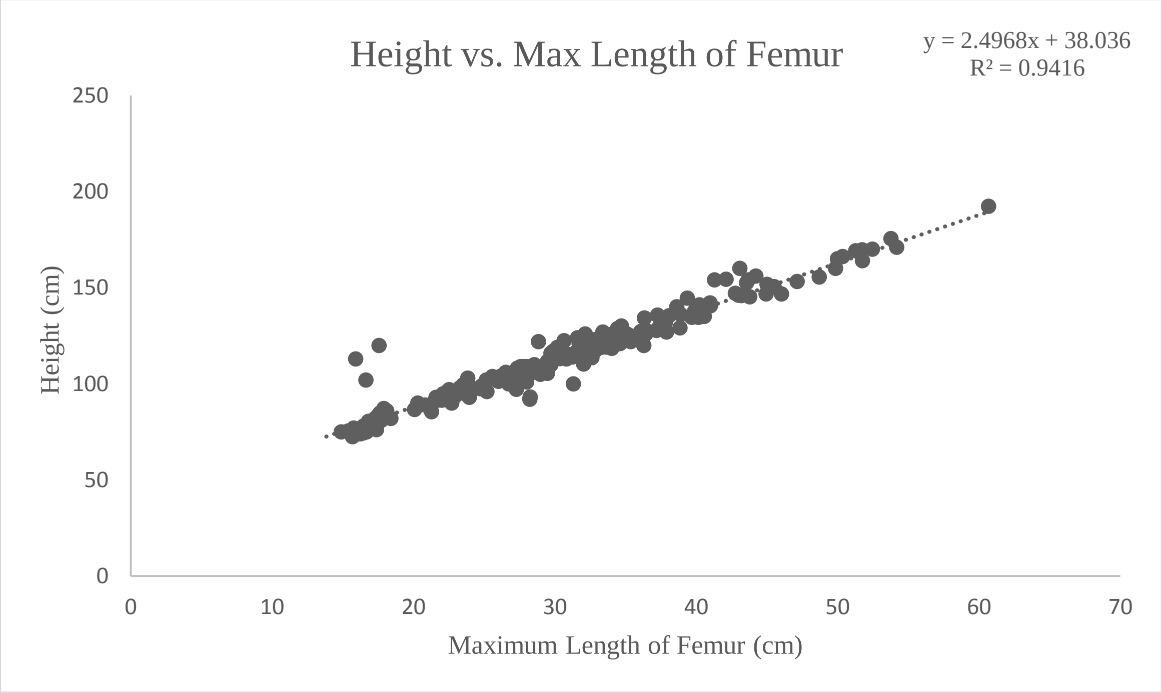


Figure 8: R^2=0.94, ANOVA F=3094.86, p < 0.001, n=194

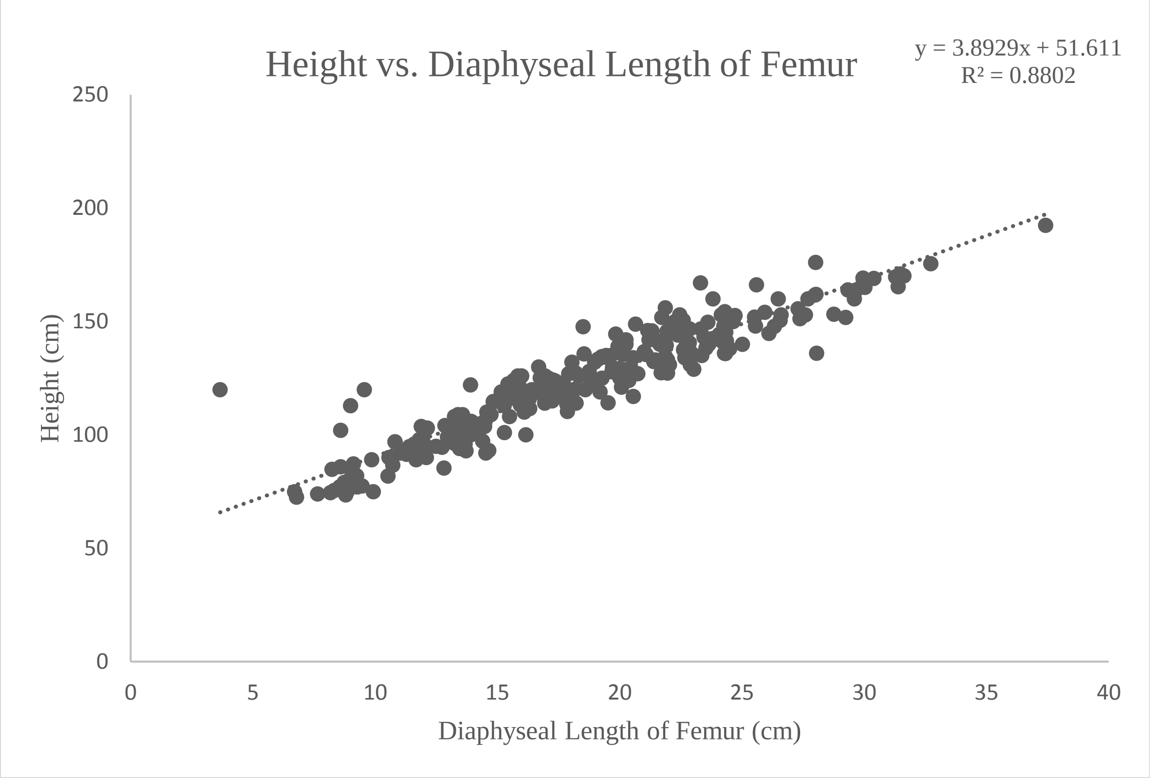


Figure 9: R^2=0.88, ANOVA F=1961.01, $p < 0.001$, n=269

Table 23: Regression formulae for stature as a variable of total maximum femoral length where y=mx+b

		Total	Maximum	Length			
Age (years)	n	Slope	Intercept	R^2	P	Standard Error	ANOVA F
1 -17	194	2.497	38.036	0.940	<0.001	5.900	3094.863
1	18	3.847	14.196	0.630	<0.001	2.706	27.217
2	23	2.653	33.303	0.899	<0.001	1.835	187.298
3	18	1.986	50.374	0.550	<0.001	3.560	19.443
4	22	1.060	75.301	0.130	0.095	4.379	3.076
5	23	2.041	51.196	0.380	0.002	5.950	13.115
6	18	2.006	54.783	0.350	0.010	3.460	8.434
7	18	1.975	54.529	0.710	<0.001	3.250	39.997
8	10	2.014	55.405	0.760	<0.001	3.660	25.613
9	7	2.974	18.263	0.940	<0.001	2.280	71.591
10	8	2.516	39.937	0.580	0.027	5.070	8.394
11	8	1.938	63.136	0.630	0.019	4.240	10.065
12	7	1.825	71.728	0.700	0.019	3.610	11.569
13	1	-	-	-	-	-	-
14	4	1.254	101.240	0.640	0.200	6.570	3.554
15	2	1.933	69.682	1.000	-	0.000	-
16	1	-	-	-	-	-	-
17	2	4.122	46.147	1.000	-	-	-

Table 24: Regression formulae for stature as a variable of diaphyseal length where y=mx+b

		Total	Diaphyseal	Length			
Age (years)	n	Slope	Intercept	R^2	P	Standard Error	ANOVA F
1 -17	269	3.893	51.611	0.880	<0.001	2.071	1961.009
1	21	4.760	41.471	0.083	0.204	0.773	1.344
2	24	2.957	56.179	0.659	<0.001	3.405	42.584
3	18	2.520	67.966	0.416	0.004	4.047	11.400
4	22	1.345	85.581	0.089	0.177	4.490	1.954
5	24	1.527	89.121	0.113	0.109	7.016	2.799
6	21	1.541	94.705	0.260	0.018	1.337	6.691
7	20	1.460	97.459	0.272	0.018	2.004	6.727
8	22	1.975	90.830	0.326	0.006	5.540	9.682
9	25	2.298	88.412	0.253	0.011	6.758	7.773
10	21	2.087	96.119	0.436	0.001	5.331	14.684
11	18	1.324	117.025	0.188	0.072	6.617	3.705
12	20	2.264	96.319	0.282	0.016	8.245	7.071
13	1	-	-	-	-	-	-
14	4	3.278	62.153	0.267	0.483	15.549	0.730
15	4	2.467	90.546	0.909	0.047	2.442	19.883
16	2	9.506	163.296	1.000	-	0.000	-
17	2	4.865	16.273	1.000	-	0.000	-

Age

Although the primary goal of this study was to create regression based formulae regardless of age, similar to Robbins Schug et al. (2013), formulae with age classes were derived for comparison purposes (Ruff, 2007). When comparing the age class formulae to the formulae without age classes, it is apparent that the latter is more accurate and precise (see Tables 20, 21, 22, 23, and 24) for this sample population. This is likely due to the limited number of subjects per annual age cohort available for this sample population. However, age class formulae were statistically significant in some cases – for example, for maximum femoral length of 2 year olds as a function of stature, n=23 was sufficient to produce a highly significant relationship between the measurement and height (R^2=0.90, ANOVA F=187.30, p<0.001). There was also the limiting nature of radiographs. As previously mentioned, subjects over a certain height generally required multiple films for femoral imaging. This restricted the number of measurements available to researchers for stature age class formulae (i.e. note the significant decrease in n in Tables 23 and 24 around the age of 13 years).

The smaller sample populations for age class regressions were also more subject to affects related to anomalies. Several subjects in this population can be categorized as obese or extremely obese. Their inclusion was necessary as obesity is becoming more and more commonplace in the United States. In the large regressions produced irrespective of age, the potential to skew analyses were limited by the other data outweighing these subject's single datum point. Small age class regressions could be easily overpowered. For example, there are two 8-year-old females whose height and weight are reported as 139 cm to 62.3 kg and 136.7 cm to 62.7 kg. The first of these subjects would have a body mass index (BMI) of 32.2, putting her in the 99th percentile for her age and sex (Division of Nutrition, Physical Activity, and Obesity: BMI Percentile Calculator for Child and Teen, 2017). The latter subject would have a BMI so high, the juvenile BMI calculator from the Centers for Disease Control and Prevention (CDC) displayed the following error message:

> Please check the accuracy of the information you entered.
> Based on the information entered, the calculated BMI is above the range of expected values and cannot be displayed on a BMI-for-age percentile growth chart. If the entries are accurate, this child is obese and further assessment by a healthcare provider is recommended.

Other subjects in the sample population reportedly similarly high BMIs. A 16-year-old male was reported to be 192.4 cm tall and weight 145 kg. Again, upon entering the appropriate age and sex with these measurements into the adolescent calculator, a BMI in the 99th percentile was reported (Division of Nutrition, Physical Activity, and Obesity: BMI Percentile Calculator for Child and Teen, 2017). It is possible that errors occurred leading to these high BMIs. Researchers could have transcribed information from subject medical charts incorrectly. Medical staff could have recorded weight in pounds instead of kilograms. -> However, this seems unlikely as use of the metric system is standard for medical practice. If this were the case, the 16-year-old male would go from having a BMI of 39.2 to 18.2 (15th percentile for age and sex).

An overlay of the BMIs for males in sample population can be seen in Figure 10, with the axes mimicking the body mass index-for-age percentiles chart for boys between 2 and 20 years old as published by the CDC. It is apparent from the overlay that there are a number of impossibilities in the sample population (that were appropriately culled from statistical analysis but included here for illustrative purposes). However, even in more clustered groups, the sample population appears to regularly enter the upper percentiles (e.g. at least two 4 year olds surpass a BMI of 18, which is the 95 percentile that age class).

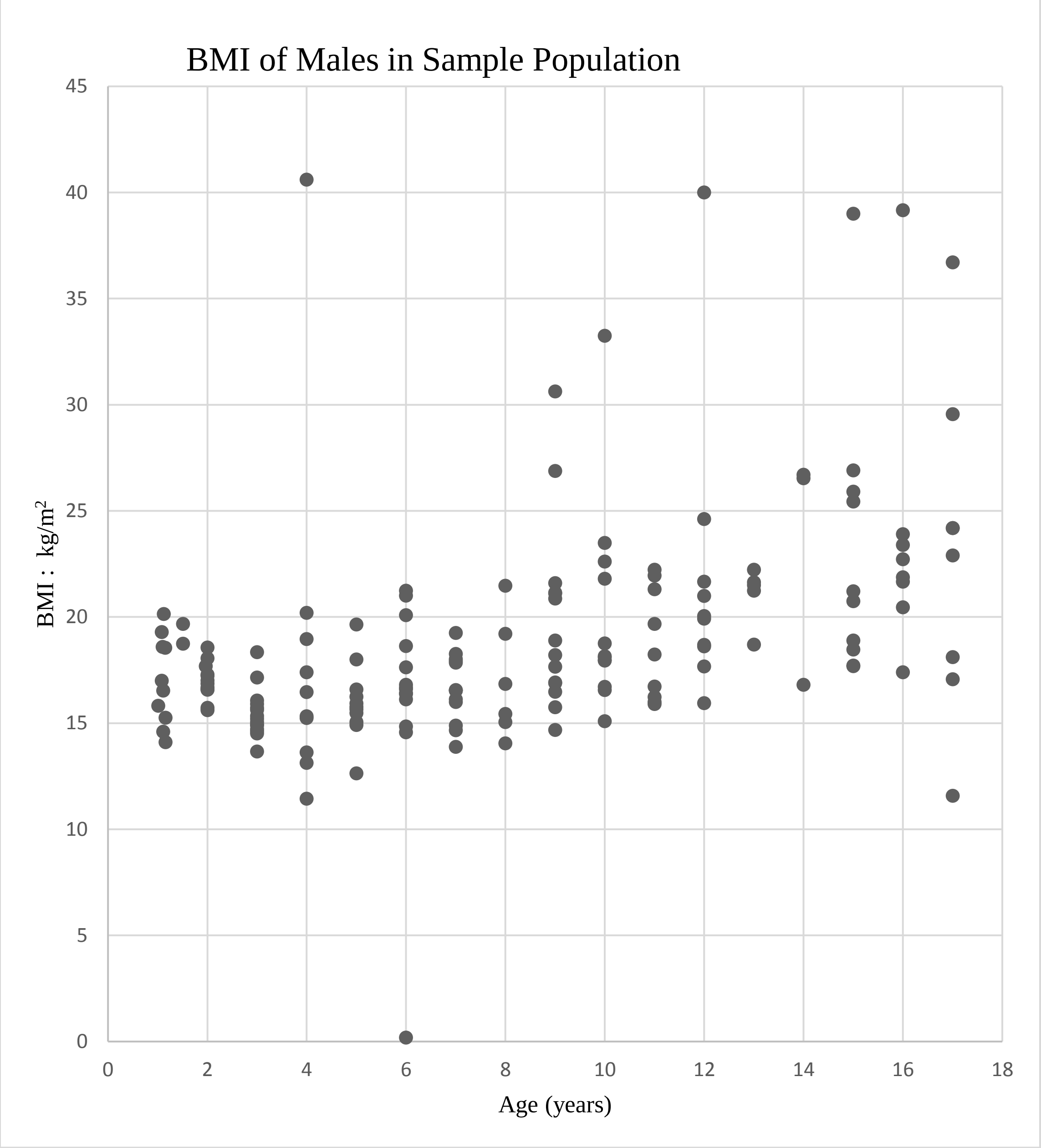


Figure 10: Body mass index for males of sample population

Sex differences

The primary goal of this study was to create regression based formulae without age based classes. Initially statistical analysis also excluded sex based categories as well since it is difficult – if not impossible – to identify the sex of a juvenile skeleton. However, after the primary analysis was completed, sex based formulae were produced for comparative purposes. Unlike age class formulae, which did not consistently meet statistical significance, all ten of the sex based formulae displayed highly statistically significant relationships (see Table 25).

Table 25: Regression formulae based on sex

Measurement	Sex	Age (years)	n	Slope	Intercept	R^2	P	Standard Error	ANOVA F
Max Length	F	1 - 17	88	2.466	38.850	0.930	<0.001	2.535	1144.303
Max Length	M	1 - 17	105	2.524	37.349	0.951	<0.001	2.103	2014.400
Diaphyseal Length	F	1 - 17	127	3.808	51.861	0.881	<0.001	2.082	928.998
Diaphyseal Length	M	1 - 17	141	3.933	52.025	0.879	<0.001	2.111	1009.489
Superoinferior Head Breath	F	1 - 17	245	1.213	4.340	0.708	<0.001	0.269	590.253
Superoinferior Head Breath	M	1 - 17	289	1.138	4.871	0.796	<0.001	0.317	1119.149
Mediolateral Head Breadth	F	1 - 17	251	0.367	3.377	0.859	<0.001	0.270	1520.899
Mediolateral Head Breadth	M	1 - 17	293	0.345	3.649	0.891	<0.001	0.236	2367.209
Mediolateral Neck Breadth	F	1 - 17	248	0.482	5.795	0.890	<0.001	0.238	1984.749
Mediolateral Neck Breadth	M	1 - 17	283	0.427	6.855	0.932	<0.001	0.184	3860.056

Racial and ethnic differences

A unique feature of this study is its diverse population. Thus, delving into possible comparisons between self-identified racial, and ethnic groups was deemed necessary. Statistical analysis was performed on six of the racial groups – those who declined to identify their race or did not know (n=89) and those who simply identified as the nebulous “other” (n=19) were not analyzed since they were not appropriately contextualized to consider any results illuminating. Unfortunately, subjects of American Indian or Alaskan Native, and Native Hawaiian or other Pacific Islander decent did not have sufficiently large populations to produce statistically significant results (n=2, n=3, respectively). Asian (n=12) had a similarly small population. For four of the five analyses, the threshold for statistical significance was not reached. However, a statistically significant relationship was noted between body mass and mediolateral head breadth (see Table 26).

Most the population identified as white (56.66%), or black or African American (19.30%). A relatively large portion also identified as “multiracial” (5.62%). All of these racial categories produced statistically significant relationships (see Tables 27, 28, and 29).

Ethnicity, specifically with regards to Hispanic and Latino ethnicity, was also considered. Of the sample population, 12.77% identified as Hispanic or Latino. This subpopulation also received statistical analysis and produced significant relationships (see Table 30).

Table 26: Regression formulae by racial category, Asian

Measurement	Age (years)	n	Slope	Intercept	R^2	P	Standard Error	ANOVA F
Mediolateral Head Breadth	1-17	8	0.3169	9.3919	0.649	0.016	0.300	11.097

Table 27: Regression formulae by racial category, White

Measurement	Age (years)	n	Slope	Intercept	R^2	P	Standard Error	ANOVA F
Max Length	1-17	117	2.474	39.337	0.953	<0.001	5.499	2322.487
Diaphyseal Length	1-17	150	3.952	50.539	0.906	<0.001	7.887	1433.713
Superoinferior Head Breath	1-17	297	1.137	4.995	0.717	<0.001	0.379	746.201
Mediolateral Head Breadth	1-17	295	0.440	6.615	0.907	<0.001	0.218	2861.027
Mediolateral Neck Breadth	1-17	301	0.345	3.609	0.911	<0.001	0.213	3042.913

Table 28: Regression formulae by racial category, Black or African American

Measurement	Age (years)	n	Slope	Intercept	R^2	P	Standard Error	ANOVA F
Max Length	1-17	28	2.397	40.637	0.899	<0.001	8.608	231.583
Diaphyseal Length	1-17	52	3.212	66.805	0.781	<0.001	11.043	178.156
Superoinferior Head Breath	1-17	107	1.209	4.061	0.728	<0.001	0.369	277.877
Mediolateral Head Breadth	1-17	108	0.338	9.063	0.576	<0.001	0.460	143.921
Mediolateral Neck Breadth	1-17	107	0.351	3.688	0.790	<0.001	0.327	393.970

Table 29: Regression formulae by racial category, Multiracial

Measurement	Age (years)	n	Slope	Intercept	R^2	P	Standard Error	ANOVA F
Max Length	1-17	14	2.805	27.026	0.899	<0.001	6.977	97.333
Diaphyseal Length	1-17	21	4.482	39.209	0.901	<0.001	7.583	173.534
Superoinferior Head Breath	1-17	34	1.235	4.050	0.755	<0.001	0.365	98.722
Mediolateral Head Breadth	1-17	34	0.406	5.839	0.920	<0.001	0.208	369.149
Mediolateral Neck Breadth	1-17	35	0.385	2.931	0.869	<0.001	0.264	218.879

Table 30: Regression formulae by ethnic category, Hispanic or Latino

Measurement	Age (years)	n	Slope	Intercept	R^2	P	Standard Error	ANOVA F
Max Length	1-17	27	2.607	33.961	0.957	<0.001	4.130	554.396
Diaphyseal Length	1-17	35	4.221	45.828	0.874	<0.001	7.054	229.285
Superoinferior Head Breath	1-17	68	1.174	4.453	0.880	<0.001	0.220	484.310
Mediolateral Head Breadth	1-17	68	0.432	6.785	0.925	<0.001	0.174	814.787
Mediolateral Neck Breadth	1-17	69	0.364	3.146	0.855	<0.001	0.252	396.365

DISCUSSION

This study created regression formulae for estimating both body mass and stature in juvenile skeletons based on five distinct measurements relying on data collected by Children's Mercy Hospital. This subject population yielded different results from previous studies, possibly due to the more racially diverse and more modern American population.

The sample population for this study relies on a "snap shot" of American children from the last decade (i.e. the hospital's digital radiography database came online in January of 2008) in the Kansas City area. As Cardoso (2009) concluded, regression formulae are not universal. Thus, aggregating information from a variety of subjects, through time, is key to producing the most reliable, accurate, and precise body mass and stature estimation methods – along with only utilizing the most contextually appropriate formulae when estimating body mass or stature (i.e. using formulae derived from a certain population only on like populations). Unlike previous studies, this study includes self-identified racial identities outside of white and African American. It also includes self-identified ethnic identity categories.

Ordinary least square regression analyses showed two distinct patterns for body mass and stature. All three body mass regressions evinced an exponential relationship between the femoral measurement and weight. Considering that Ruff (2007), Robbins et al. (2010), and Robbins Schug et al. (2013) reported a similar exponential relationship when examining body mass, this result was not unexpected. The exponential pattern reflects the growth of the child and the limits on their individual bone growth. Of the predictor variables, mediolateral femoral neck breadth had the strongest relationship with body mass in this study– a notable difference from previous studies.

Ruff considered, body mass as a function of femoral metaphyseal breadth (SEE=0.65 prior to logarithmic transformation), femoral head breadth (SEE=1.35 prior to logarithmic transformation), bi-iliac breadth and femur length (SEE=6.7), bi-iliac breadth and tibia length (SEE=6.6), bi-iliac breadth and humerus length (SEE=6.8), and bi-iliac breadth and radius length (SEE=5.0). The metaphyseal breadth outperformed the other formulae (Ruff, 2007). Robbins et al (2010) solely examined body mass in relation to the torsional rigidity of the femur – the SEE for their age formulae ranged from as low as 0.27 to as high as 8.13. Standard error generally increased with age with a noticeable increase between age classes 8 and 9 years old (SEE=1.75 and 4.11, respectively) (Robbins, Sciulli, & Blatt, 2010). Robbins Schug et al. (2013) examined torsional rigidity (SEE=5.9), femoral head diameter, and breadth of distal metaphysis (SEE=4.8). The femoral head diameter did not consistently produce results for all age classes (i.e. it could not be used for children before the age of 6 years old). The trend gleaned from the studies suggests the breadth of the distal metaphysis is the most reliable indicator of body mass in juveniles.

For stature, two regressions were performed – one utilizing total maximum femoral length and another using diaphyseal femoral length. Each had a linear relationship with height. Both relationships were statistically significant ($p<0.001$), but a stronger correlation is apparent when also accounting for R^2 between height and total maximum length (R^2=0.94) than diaphyseal length (R^2=0.88). The linear relationship between both measurements and stature is sensible when considering the femur directly contributes to an individual's overall height. Furthermore, the conclusion this study reached with regards to the maximum length agrees with the general findings of studies performed on adult and juvenile stature (Trotter & Gleser, 1952; Telkka, Palkama, & Virtama, 1962; Feldesman M. R., 1992; Ruff, 2007)

Comparing to Previous Studies

To gauge the reliability of the estimation formulae generated by this study, they were compared to formulae from current literature – Feldesman (1992), Ruff (2007), Smith (2007), Schug (2013) were chosen because their formulae best reflect those available to investigators working on forensics cases. Furthermore, each study has at least one measured metric in common with this study, allowing like formulae to be compared. When an age or sex cohort was utilized in the comparison study, the comparable age or sex cohort was used from this study. Similarly, only formulae produced from the same or comparable measurements were examined together – only stature estimation formulae created using total maximum femoral length were compared to stature estimation formulae using total maximum femoral length and so on.

Lacking an independent population with which to verify results, attempts were made to create the least biased comparisons possible. Four subjects were chosen from this study's sample population with regard to only two factors. The first required that all comparisons made attempted to meet the criteria for the original study. For example, Feldesman (1992) only used measurements from 8 to 18 year olds, thus any verification against his formulae could only be valid if the test subject is also from this age range. The second requirement was simply that the test subject must have a complete measurement for each of the five femoral measurements, in addition to a recorded height and weight, to perform the most indicative test possible.

Utilizing the estimation formulae, a known independent variable – a femoral measurement – was inserted and a dependent variable – stature or body mass – was solved for. The resulting number was then compared to the observed dependent variable associated with the test subject, solving for the difference. This difference was then turned into a percent of that known dependent variable to determine the percent difference between the estimated dependent variable and the known dependent variable. The percent differences between published studies and this study were analyzed. This study more closely approximated known elements of stature or body mass in six of the eight comparisons. This may be due to a biased test population – although randomly selected, test subjects for these comparisons are from this study and directly influence the formulae being tested (see Table 31).

Table 31: Comparison of Pinkston regression formulae against Feldesman (1992), Ruff (2007), Smith (2007), Robbins Schug et al. (2013)

Study ID	Measured Independent Variable	Observed Dependent Variable	Feldesman Estimate (% Difference)	Pinkston Estimate (% Difference)
3719	45.51 cm	150.60 cm	150.60 cm (11.96)	151.16 cm (0.37)
19	60.68 cm	192.40 cm	223.91 cm (16.38)	190.53 cm (0.97)
			Ruff Estimate (% Difference)	Pinkston Estimate (% Difference)
1056	22.08 cm	94.80 cm	100.62 cm (6.13)	91.88 cm (3.08)
2818	3.49 cm	26.90 kg	25.33 kg (5.85)	26.86 cm (0.14)
			Smith Estimate (% Difference)	Pinkston Estimate (% Difference)
1056	22.08 cm	94.80 cm	101.69 cm (7.26)	93.09 cm (1.81)
3719	45.51 cm	150.60 cm	170.18 cm (13.00)	151.67 cm (0.71)
2818	32.14 cm	126.00 cm	131.52 cm (4.38)	118.09 cm (6.28)
			Robbins Schug Estimate (% Difference)	Pinkston Estimate (% Difference)
2818	3.49 cm	26.90 kg	30.02 kg (11.58)	31.69 kg (17.81)

Test subjects were chosen from the sample population. The study identification numbers are as follows – 19, 1056, 2818, and 3719. Subject #19 was a 16-year-old male whose observed stature is equal to 192.4 cm and whose femur totals 60.68 cm in length. Subject #19 was relied on once to compare Feldesman's (1992) stature ratio in juvenile males. Subject #3719 was also used once, also in Feldesman. She was a 14-year-old, approximately 150.6 cm tall, with a femur measuring 45.1 cm in total length. Subject

#1056 was a 2-year-old male whose height (94.8 cm) and total femur length (22.08 cm) was analyzed twice for stature calculations – versus Ruff (2007) and Smith (2007). Finally, subject #2818 was used three times. She was a 7-year-old female who weighed 26.9 kg and is 126.0 cm tall. Her total femoral length is measured at 32.14 cm; its mediolateral head breadth is measured at 3.49 cm.

In the six instances where this study more closely estimated the dependent variables, the smallest percent difference between this study and the one it was compared to was 3.05%. The greatest percent difference was 15.41%. The mean between percent differences was 8.92% (n=6). In the two comparisons where this study did not more closely estimate the known dependent variable, the smallest percent differences was +1.9%; the largest was +6.23%. In the latter analysis, neither body mass estimation formulae approximated the known value within a 10% difference (11.59% by Schug et al.; 17.81% by Pinkston).

It is important to note here that these estimates are biased as the population for comparisons were utilized in the formation of formulae for this study, meaning the Pinkston estimates are more likely to perform better against other studies. Thus, the current comparisons look promising but cannot be considered reliable until an independent population – one that neither study relies on – can be used to test the accuracy, precision, and reliability of each of the formulae.

Comparing General Formulae to Sex based Formulae

To compare the general formulae, produced without age or sex classes, to the sex class formulae, five subjects from this study were selected for each sex and represented a variety of ages (see Table 32 for subject information). Their measurements were utilized to estimate their body mass, and stature. The resulting estimates were then compared to the observed weights and heights, and the difference between the estimated and observed values divided by the observed value to determine the percent difference (see Tables 33, 34, 35, 36, and 37). The differences between estimated and observed values were also averaged to determine the average number of units the formulae over/underestimated body mass, and stature.

When tested, it is apparent that earlier assertions that the formulae relying on maximum femoral length, and mediolateral neck breadth are more reliable in estimating stature, and body mass, respectively, remains accurate. When comparing formulae on an individual basis, sex specific formulae and general formulae performed similarly well – or poorly.

However, when examined together, patterns emerge. Within categories, only male test subjects showed any age-related patterns. When looking at mediolateral head breadth, and superoinferior head breadth, the first three test subjects had more accurate estimations using the general formulae. Note the subjects range in age from 3 to 10 years old. The later subjects – 14 and 17 years old – are more closely estimated using the sex specific formulae in both categories. This pattern suggests for these measurements at least there is an age-related component – probably related to the onset of puberty that likely increases the accuracy of the sex specific formulae.

The general formulae had lower average errors for both males and females when examining body mass via superoinferior head breadth and mediolateral neck breadth. Sex specific formulae outperformed general formulae in total maximum length and mediolateral head breadth. The average error for diaphyseal length includes no pattern – the error is lower for the general formula when examining males and higher than the sex specific formulae when examining females.

Table 32: Age, height, weight, maximum femur length, diaphyseal length, superoinferior head breadth, mediolateral head breadth, and mediolateral neck breadth of five female and five male test subjects, by age

Study ID	Sex	Age (years)	Height (cm)	Weight (kg)	Total Maximum Length (cm)	Diaphyseal Length (cm)	Superoinferior Head Breadth (cm)	Mediolateral Head Breadth (cm)	Mediolateral Neck Breadth (cm)
1057	F	2	86.60	13.00	20.07	10.72	0.96	1.68	3.83
5	F	5	114.10	23.90	31.62	19.52	2.86	1.63	4.89
2941	F	8	127.80	24.80	37.19	19.68	1.94	3.44	6.43
3600	F	13	153.20	36.20	47.13	28.76	1.83	4.68	6.03
16	F	15	154.10	50.10	43.67	25.94	1.94	4.96	5.98
3	M	3	99.40	13.50	23.52	13.31	2.08	1.11	4.24
2660	M	6	124.00	22.40	31.60	15.61	1.56	2.82	5.24
3276	M	10	135.70	27.80	37.26	18.54	1.58	3.44	6.02
3724	M	14	171.00	78.10	54.17	31.48	1.82	5.08	6.69
4121	M	17	175.50	55.80	53.77	32.73	1.71	4.75	7.70

Table 33: Comparison of general and sex specific formulae by females and males, for stature as a function of total maximum femoral length

Study ID	Measured Independent Variable	Observed Dependent Variable	General Formulae Estimate (% Difference)	Sex Specific Formulae Estimate (% Difference)
1057	20.07	86.60	88.15 (1.79)	88.33 (2.00)
5	31.62	114.10	116.99 (2.53)	116.81 (2.37)
2941	37.19	127.80	130.89 (2.42)	130.54 (2.12)
3600	47.13	153.20	155.71 (1.64)	155.05 (1.21)
16	43.67	154.10	147.07 (4.56)	146.52 (4.92)
		Average Error	±3.40	±3.32
3	23.52	99.40	96.76 (2.66)	96.72 (2.69)
2660	31.60	124.00	116.94 (5.70)	117.12 (5.48)
3276	37.26	135.70	131.07 (3.41)	131.41 (3.16)
3724	54.17	171.00	173.29 (1.34)	174.10 (1.81)
4121	53.77	175.50	172.29 (1.83)	173.09 (1.38)
		Average Error	±3.97	±3.87

Table 34: Comparison of general and sex specific formulae by females and males, for stature as a function of diaphyseal length

Study ID	Measured Independent Variable	Observed Dependent Variable	General Formulae Estimate (% Difference)	Sex Specific Formulae Estimate (% Difference)
1057	10.72	86.60	93.34 (7.79)	92.28 (7.02)
5	19.52	114.10	127.60 (11.83)	126.18 (10.59)
2941	19.68	127.80	129.39 (1.25)	126.79 (0.79)
3600	28.76	153.20	163.57 (6.77)	161.37 (5.33)
16	25.94	154.10	152.59 (0.98)	150.63 (2.53)
		Average Error	±6.74	±6.12
3	13.31	99.40	103.43 (4.05)	104.38 (5.01)
2660	15.61	124.00	112.57 (9.22)	113.62 (8.37)
3276	18.54	135.70	123.79 (8.78)	124.95 (7.92)
3724	31.48	171.00	174.16 (1.85)	175.85 (2.83)
4121	32.73	175.50	179.03 (2.01)	180.76 (3.00)
		Average Error	±6.81	±7.24

Table 35: Comparison of general and sex specific formulae by females and males, for body mass as a function of superoinferior head breadth

Study ID	Measured Independent Variable	Observed Dependent Variable	General Formulae Estimate (% Difference)	Sex Specific Formulae Estimate (% Difference)
1057	0.96	13.00	14.24 (9.56)	13.91 (6.99)
5	2.86	23.90	131.08 (448.46)	139.41 (483.30)
2941	1.94	24.80	44.75 (80.44)	45.67 (84.14)
3600	1.83	36.20	39.35 (8.71)	39.96 (10.39)
16	1.94	50.10	44.75 (10.68)	45.67 (8.85)
		Average Error	±27.37	±29.10
3	2.08	13.50	52.70 (290.38)	85.41 (532.66)
2660	1.56	22.40	28.71 (28.16)	41.74 (86.33)
3276	1.58	27.80	29.39 (5.71)	42.90 (54.33)
3724	1.82	78.10	38.90 (50.20)	59.71 (23.55)
4121	1.71	55.80	34.21 (38.70)	51.31 (8.04)
		Average Error	±21.52	±25.85

Table 36: Comparison of general and sex specific formulae by females and males, for body mass as a function of mediolateral head breadth

Study ID	Measured Independent Variable	Observed Dependent Variable	General Formulae Estimate (% Difference)	Sex Specific Formulae Estimate (% Difference)
1057	1.68	13.00	14.09 (8.35)	13.03 (2.20)
5	1.63	23.90	13.79 (42.28)	12.72 (46.79)
2941	3.44	24.80	29.39 (18.53)	30.44 (22.75)
3600	4.68	36.20	49.36 (36.35)	55.35 (52.91)
16	4.96	50.10	55.49 (10.76)	63.35 (26.46)
		Average Error	±6.866	±9.852
3	1.11	13.50	11.10 (17.78)	11.06 (18.40)
2660	2.82	22.40	22.68 (1.27)	22.87 (2.19)
3276	3.44	27.80	29.40 (5.74)	29.81 (7.24)
3724	5.08	78.10	58.34 (25.30)	60.08 (23.07)
4121	4.75	55.80	50.83 (8.92)	52.18 (6.49)
		Average Error	±5.80	±5.32

Table 37: Comparison of general and sex specific formulae by females and males, for body mass as a function of mediolateral neck breadth

Study ID	Measured Independent Variable	Observed Dependent Variable	General Formulae Estimate (% Difference)	Sex Specific Formulae Estimate (% Difference)
1057	3.83	13.00	13.73 (5.59)	13.66 (5.06)
5	4.89	23.90	19.95 (17.65)	19.67 (17.66)
2941	6.43	24.80	34.36 (38.54)	33.46 (34.91)
3600	6.03	36.20	29.34 (17.58)	29.15 (19.48)
16	5.98	50.10	29.31 (41.49)	28.65 (42.81)
		Average Error	±8.28	±8.41
3	4.24	13.50	15.86 (17.50)	15.73 (16.52)
2660	5.24	22.40	22.58 (0.79)	22.20 (0.88)
3276	6.02	27.80	29.73 (6.94)	29.05 (4.49)
3724	6.69	78.10	37.66 (51.78)	36.59 (53.14)
4121	7.70	55.80	53.78 (3.60)	51.83 (7.12)
		Average Error	±9.38	±9.83

Comparing General Formulae to Racial and Ethnicity based Formulae

To compare the general formulae, produced without regard to race or ethnicity, to the race class and ethnicity class formulae, four subjects from this study were selected, two per sex representing varying of ages for each of the four race categories, and one ethnicity category (see Table 38 for subject information). Their measurements were utilized to estimate body mass, and stature. Again, estimates were compared to the observed weights and heights and the difference between the estimated and observed values divided by the observed value to determine the percent difference (see Table 39, 40, 41, 42, and 43). The differences between estimated and observed values were also averaged to determine the average number of units the formulae over/underestimated body mass, and stature.

When tested, it is clear the formulae relying on maximum femoral length, and mediolateral neck breadth to estimate stature, and body mass, respectively, remain the most reliable. Some estimations for test subjects come out outlandishly large, regardless of formulae used. This was also true in sex specific formulae as well.

Again, general formulae and the categorized formulae work approximately the same. When examining formulae across categories, a few patterns emerge. First, stature is more reliably estimated using the general formulae when relying on the diaphyseal measurement. This is true for white, African American, multiracial, and Hispanic or Latino subjects. All four of the race or ethnicity specific formulae for diaphyseal length have higher standard errors of estimate than the general formula. In contrast, when using total maximum femoral length to estimate stature, the race or ethnicity specific formulae all more closely estimated the observed height of the test subject. However, the associated SEEs were only lower than that of the general formula for whites and Hispanics or Latinos. African American and multiracial formulae had notably higher SEEs than the general formula for this measurement.

Measurements associated with body mass did not reveal any patterns in individual categories or across categories.

Table 38: Age, height, weight, maximum femur length, diaphyseal length, superoinferior head breadth, mediolateral head breadth, and mediolateral neck breadth of test subjects, by age, sex, and race or ethnicity

Study ID	Sex	Age (years)	Race or Ethnicity	Height (cm)	Weight (kg)	Total Maximum Length (cm)	Diaphyseal Length (cm)	Superoinferior Head Breadth (cm)	Mediolateral Head Breadth (cm)	Mediolateral Neck Breadth (cm)
2248	F	4	Asian	115.00	16.80	31.68	17.24	1.33	2.60	5.20
5	F	5	Asian	114.10	23.90	31.62	19.52	2.86	1.63	4.89
3301	M	10	Asian	-	22.70	36.79	19.77	1.76	3.91	4.80
3605	M	13	Asian	169	61.80	-	27.26	1.65	4.66	6.90
1061	F	2	White	92.00	15.56	21.58	11.02	1.06	1.93	4.33
2667	M	6	White	123.00	22.45	32.79	17.69	1.39	3.04	5.77
3536	F	12	White	155.60	46.70	48.71	27.29	1.70	4.45	7.90
4121	M	17	White	175.50	55.80	53.77	32.73	1.71	4.75	7.70
1874	M	3	Black/AA	96.00	14.80	25.19	12.00	1.51	2.30	4.59
2841	F	7	Black/AA	134.80	34.20	40.07	22.78	1.73	4.03	6.36
3338	M	10	Black/AA	134.60	39.50	40.17	21.86	1.68	3.81	6.43
3878	F	15	Black/AA	169.70	70.10	51.74	31.29	1.93	4.96	7.44
2232	F	3	Multiracial	102.20	15.10	26.15	13.51	1.50	2.37	4.55
2485	F	5	Multiracial	114.50	18.40	31.55	15.12	1.44	2.72	5.21
2970	M	8	Multiracial	136.10	28.60	38.90	22.93	1.76	3.94	6.48
3347	M	10	Multiracial	154.40	44.70	42.11	24.30	1.77	4.32	7.25
1054	F	2	Hispanic or Latino	91.50	17.05	22.01	11.95	1.06	1.78	3.40
2684	M	6	Hispanic or Latino	128.70	29.20	34.44	20.21	1.56	3.00	6.94
3370	M	10	Hispanic or Latino	134.20	32.70	36.34	19.46	1.55	3.53	6.10
3435	F	11	Hispanic or Latino	156.00	52.20	44.21	21.86	1.88	4.69	8.06

Table 39: Comparison of general and Asian specific for body mass as a function of mediolateral head breadth

Study ID	Measured Independent Variable	Observed Dependent Variable	General Formulae Estimate (% Difference)	Asian Specific Formulae Estimate (% Difference)
2248	2.60	16.80	20.69 (23.16)	21.41 (27.47)
5	1.63	23.90	13.79 (42.28)	15.75 (34.12)
3301	3.91	22.70	35.78 (57.60)	32.44 (42.90)
3605	4.66	61.80	48.95 (20.08)	41.14 (33.42)
		Average Error	±9.98	±10.79

Table 40: Comparison of general and White specific regression formulae

Study ID	Measured Independent Variable	Observed Dependent Variable	General Formulae Estimate (% Difference)	White Specific Formulae Estimate (% Difference)
			Maximum Length	
1061	21.58	92.00	91.92 (0.09)	92.72 (0.79)
2667	32.79	123.00	133.48 (8.52)	120.46 (2.07)
3536	48.71	155.60	159.66 (2.61)	159.84 (2.73)
4121	53.77	175.50	185.86 (5.91)	172.36 (1.79)
		Average Error	±6.24	±2.66
			Diaphyseal Length	
1061	11.02	92.00	94.51 (2.73)	94.09 (2.27)
2667	17.69	123.00	120.48 (2.05)	120.45 (2.07)
3536	27.29	155.60	157.85 (1.44)	158.39 (1.80)
4121	32.73	175.50	179.03 (1.79)	179.89 (2.50)
		Average Error	±2.70	±2.96
			Superoinferior Head Breadth	
1061	1.06	15.56	16.01 (2.88)	21.27 (36.71)
2667	1.39	22.45	23.54 (4.84)	33.40 (48.77)
3536	1.70	46.70	33.81 (27.60)	51.02 (9.26)
4121	1.71	55.80	34.21 (38.20)	51.73 (7.30)
		Average Error	±9.01	±6.26
			Mediolateral Head Breadth	
1061	1.93	15.56	15.64 (0.49)	15.43 (0.81)
2667	3.04	22.45	24.87 (10.77)	25.12 (11.91)
3536	4.45	46.70	44.84 (0.09)	46.66 (0.09)
4121	4.75	55.80	50.83 (4.61)	53.23 (4.61)
		Average Error	±2.33	±1.35
			Mediolateral Neck Breadth	
1061	4.33	15.56	16.38 (5.24)	16.18 (3.98)
2667	5.77	22.45	27.22 (21.25)	26.65 (18.70)
3536	7.90	46.70	57.72 (23.60)	55.74 (19.37)
4121	7.70	55.80	53.79 (3.61)	52.01 (6.79)
		Average Error	±4.65	±4.11

Table 41: Comparison of general and Black specific regression formulae

Study ID	Measured Independent Variable	Observed Dependent Variable	General Formulae Estimate (% Difference)	Black Specific Formulae Estimate (% Difference)
			Maximum Length	
1874	25.19	96.00	100.93 (5.14)	101.01 (5.22)
2841	40.07	134.80	138.08 (2.44)	136.67 (1.39)
3338	40.17	134.60	138.33 (2.77)	136.91 (1.72)
3878	51.74	169.70	167.22 (1.46)	164.64 (2.98)
		Average Error	±3.61	±3.56
			Diaphyseal Length	
1874	12.00	96.00	98.33 (2.42)	105.35 (9.74)
2841	22.78	134.80	140.29 (4.07)	139.98 (3.84)
3338	21.86	134.60	136.71 (1.57)	137.03 (1.80)
3878	31.29	169.70	173.42 (2.19)	167.32 (1.40)
		Average Error	±3.41	±4.84
			Superoinferior Head Breadth	
1874	1.51	14.80	27.08 (82.97)	25.21 (70.32)
2841	1.73	34.20	35.01 (2.38)	32.89 (3.85)
3338	1.68	39.50	33.03 (16.39)	30.96 (21.62)
3878	1.93	70.10	44.23 (36.90)	41.88 (40.25)
		Average Error	±11.36	±12.12
			Mediolateral Head Breadth	
1874	2.30	14.80	18.25 (23.33)	19.67 (32.93)
2841	4.03	34.20	37.62 (9.99)	35.24 (3.05)
3338	3.81	39.50	34.31 (13.13)	32.72 (17.15)
3878	4.96	70.10	55.49 (20.84)	48.22 (31.22)
		Average Error	±6.67	±8.64
			Mediolateral Neck Breadth	
1874	4.59	14.80	17.95 (21.28)	18.47 (24.807)
2841	6.36	34.20	33.52 (1.99)	34.38 (0.53)
3338	6.43	39.50	34.36 (13.01)	35.24 (10.80)
3878	7.44	70.10	49.07 (30.00)	50.23 (28.35)
		Average Error	±7.50	±7.00

Table 42: Comparison of general and multiracial specific regression formulae

Study ID	Measured Independent Variable	Observed Dependent Variable	General Formulae Estimate (% Difference)	Multiracial Specific Formulae Estimate (% Difference)
			Maximum Length	
2232	26.15	102.20	103.33 (1.10)	100.38 (1.78)
2485	31.55	114.50	116.81 (2.02)	115.53 (0.90)
2970	38.90	136.10	135.16 (0.69)	136.15 (0.04)
3347	42.11	154.40	143.18 (7.27)	145.15 (5.99)
		Average Error	±3.90	±3.44
			Diaphyseal Length	
2232	13.51	102.20	104.20 (1.96)	104.28 (2.04)
2485	15.12	114.50	110.47 (3.52)	112.04 (2.15)
2970	22.93	136.10	140.88 (3.51)	149.65 (9.96)
3347	24.30	154.40	146.21 (5.31)	156.25 (1.20)
		Average Error	±4.78	±4.99
			Superoinferior Head Breadth	
2232	1.50	15.10	26.76 (77.25)	25.82 (70.78)
2485	1.44	18.40	24.95 (35.61)	23.97 (30.30)
2970	1.76	28.60	36.26 (26.80)	35.59 (24.46)
3347	1.77	44.70	36.69 (17.92)	36.04 (19.38)
		Average Error	±8.47	±7.99
			Mediolateral Head Breadth	
2232	2.37	15.10	18.79 (24.47)	17.81 (17.97)
2485	2.72	18.40	21.76 (18.23)	21.00 (14.14)
2970	3.94	28.60	36.23 (26.67)	37.29 (30.39)
3347	4.32	44.70	42.46 (5.00)	44.59 (0.24)
		Average Error	±4.23	±3.53
			Mediolateral Neck Breadth	
2232	4.55	15.10	17.70 (17.20)	16.91 (12.00)
2485	5.21	18.40	22.34 (21.41)	21.81 (18.52)
2970	6.48	28.60	34.97 (22.47)	35.57 (27.37)
3347	7.25	44.70	45.89 (2.66)	47.85 (7.05)
			±3.52	±3.83

Table 43: Comparison of general and Hispanic/Latino specific regression formulae

Study ID	Measured Independent Variable	Observed Dependent Variable	General Formulae Estimate (% Difference)	Hispanic/Latino Specific Formulae Estimate (% Difference)
			Maximum Length	
1054	22.01	91.50	92.99 (1.63)	91.34 (0.18)
2684	34.44	128.70	124.03 (3.63)	123.74 (3.85)
3370	36.34	134.20	128.77 (4.05)	128.69 (4.10)
3435	44.21	156.00	148.42 (4.86)	149.21 (4.35)
		Average Error	±4.79	±4.35
			Diaphyseal Length	
1054	11.95	91.50	98.13 (7.25)	96.27 (5.21)
2684	20.21	128.70	130.29 (1.23)	131.14 (1.89)
3370	19.46	134.20	127.37 (5.09)	127.97 (4.64)
3435	21.86	156.00	136.71 (12.37)	138.10 (11.47)
		Average Error	±8.59	±7.83
			Superoinferior Head Breadth	
1054	1.06	17.05	16.01 (6.11)	15.45 (9.37)
2684	1.56	29.20	28.71 (1.69)	27.79 (4.84)
3370	1.55	32.70	28.37 (13.23)	27.46 (16.02)
3435	1.88	52.20	41.72 (20.08)	40.45 (22.50)
		Average Error	±4.08	±5.00
			Mediolateral Head Breadth	
1054	1.78	17.05	14.69 (13.86)	14.64 (14.14)
2684	3.00	29.20	24.46 (16.25)	24.80 (15.08)
3370	3.53	32.70	30.52 (6.66)	31.18 (4.66)
3435	4.69	52.20	49.57 (5.05)	51.46 (1.42)
		Average Error	±2.98	±2.27
			Mediolateral Neck Breadth	
1054	3.40	17.05	11.79 (30.83)	11.78 (30.93)
2684	6.94	29.20	41.13 (40.87)	42.72 (46.30)
3370	6.10	32.70	30.58 (6.48)	31.47 (3.77)
3435	8.06	52.20	61.07 (17.00)	64.22 (23.03)

Study ID	Measured Independent Variable	Observed Dependent Variable	General Formulae Estimate (% Difference)	Hispanic/Latino Specific Formulae Estimate (% Difference)
		Average Error	±7.05	±8.01

Suggested Use of Results

It is suggested that the formulae produced in this study be used cautiously, and only be applied to applicable populations. Selecting the correct formula from those listed is of key importance. Although the sex, age, race, and ethnicity formulae performed similarly when compared to the general formulae, the general formulae should only be utilized when no other information for a decedent is known or when it is statistically logical to do so. The general formulae are more linear with high R^2s and low p values. However, these values come at a cost when examining juveniles from 1 to 17 years old – very high standard errors of estimate. For example, the general formula estimating stature based on total maximum femur length has a standard error of estimate of 5.900 cm compared to age categories, SEEs range from 1.835 (2 year olds) to 6.570 (14 year olds); sex specific formulae produce SEEs of 2.103 for males and 2.535 for females. Thus, it would be appropriate to rely on an age specific formula even if it was less linear if the SEE was noticeably lower than that of the general formula. This is also true for sex specific formula. Formulae based on self-identified racial, and ethnicity categories should be approached more cautiously.

While stature formulae relying on total maximum femur length had lower SEEs for whites, and Hispanics or Latinos, they did not for African Americans or people identifying as multiracial. If no other information is known about the decedent, a general formula may better serve an observer than using either African American or multiracial formulae in this situation. Diaphyseal formulae derived from racial or ethnicity categories should be disregarded. They were no more or less linear than general formulae, and all had higher SEEs.

However, again, this rule should be applied thoughtfully. When estimating body mass, all categorizations – age, sex, race, and ethnicity – produced significantly smaller SEEs than the general formula based on mediolateral neck breath (12.669 kg). All SEEs for these categories were 0.327 (for African Americans) or less, providing greater confidence levels to the less linear equations.

In forensic cases

The intended use of these formulae, as indicated at the beginning of this study, is to aid in identification of juvenile remains in forensic cases. The bony landmarks required for measurement are previously outlined in Methods. However, orientation of the femur for these measurements must be discussed. Measurements from this study were applied to radiographs. Radiographs of the femur were taken in the anterior to posterior. It should be noted femoral radiographs are taken supine except in specific instances where weight bearing in required for limb alignment. Instances involving particularly young subjects frequently included an adult hand in the radiograph. In such instances, measurements were collected where the overlaying boney structure from the hand did not interfere with the quality of the measurement.

Provided these caveats, before measurements described in this study are taken, the femur should be laid with its anterior surface down, it posterior surface facing up toward the observer (see Figure 11). All measurements should be taken parallel to the surface used and not in the same plane as the bone being examined in order to best approximate the angles associated with x-ray creation.

Figure 11: 3D printed femur, courtesy Mercy Children's Hospital, its posterior surface facing up toward the observer

Total maximum femoral length is the distance between the most distal point of the medial epicondyle of the femur and the most proximal point of the femoral head. Since proximal and distal epiphyses were included in this measurement, if they are available in a forensics case but not fused, they should be articulated and included in this measurement. If they are not available, this measurement should not be utilized. The recommended tool for this measurement is an osteoboard.

Diaphyseal length effectively measured the distance from the rounded upper shaft to the flattened lower shaft of the femur, with measurement starting after the pectineal line and ending superior to the supracondylar ridge. This measurement did not include proximal or distal epiphyses, regardless of state of fusion, thus making it appropriate to use even in cases where epiphyses may not have been recovered. Ideal tools for this measurement depend on the age of the individual. Femurs from younger juveniles could easily be measured with a sliding caliper. Older juveniles would likely require the use of a tape measure (see Figure 12).

Figure 12: Diaphyseal measurement of 3D printed femur, courtesy Mercy Children's Hospital, in posterior view

Superoinferior head breadth was measured from the most proximal point of the femoral head to the most distal point of head. This measurement should be taken utilizing sliding calipers (see Figure 13).

Figure 13: Superoinferior head breadth measurement of 3D printed femur, courtesy of Mercy Children's Hospital, in posterior view

Mediolateral head breadth mirrors the measurement of superoinferior head breadth, whereas this measurement lies on the horizontal axis or in the transverse plane. Again, sliding calipers should be used (see Figure 14).

Figure 14: Mediolateral head breadth of 3D printed femur, courtesy of Mercy Children's Hospital, in posterior view

Finally, mediolateral neck breadth was measured from the most medial point to the most lateral point of the femoral neck, perpendicular to the long axis of the bone. Like total maximum length, epiphyses were included for this measurement thus making it only useable when epiphyses are available. If the epiphyses not fused and cannot be articulated well or are not available, this measurement is not recommended. Again, sliding calipers are used (see Figure 15).

Figure 15: Mediolateral neck breadth measurement of 3D printed femur, courtesy of Mercy Children's Hospital, in posterior view, whereas the measurement is complete due to a missing epiphysis

Future Research

This study has only marked upon the many avenues for further exploration in the study of juvenile body mass, and stature prediction models. As mentioned previously, these models – and any other model – cannot be universally applicable, meaning that data must constantly be collected, and new formulae produced to best control for secular population trends and the particularities of discreet populations. Future research exploring this or related topics can interrogate the relationships between not only the femur and body mass, and stature, but other long bones as well; the complex interplay between environment and bone plasticity through socioeconomic status; the validity of all these formulae with a thorough vetting via an independent population; and the potential implications of racial, and ethnicity organizational systems.

Future studies should explore the inclusion of other long bones, and measurements, similar to studies performed previously, but for time limitations could not be performed for this study, such as bi-iliac pelvis breadth in relation to body mass (Ruff, 2007). The measurements of this study should also be considered when creating a new study. For example, the mediolateral neck breadth was the most reliable of the measurements here for estimating body mass. It did not appear in the juvenile body mass estimation literature prior. However, diaphyseal length and mediolateral head breadth, measurements added to this study after its conception, proved less useful. Their inclusion in future research is not necessarily recommended – they may be useful when other, more reliable and accurate measurements cannot be utilized, such as total maximum length.

Future studies should also consider how each bone may be impacted by factors other than genetics (e.g. Cardoso’s study indicated the humerus may be more useful in chronically undernourished children) (Cardoso, 2009). Further exploring this relationship may impact categorization of formulae in the future between the modern socioeconomically advantaged populations and less socioeconomically advantaged.

Arguably the most important of all future research is testing these formulae against independent populations. Previous juvenile studies largely rely on the same populations – the Denver Growth Study, and the Franklin County Collection – for creation. This study relies on an independently created population but none of these formulae have been tested on a population outside of these. Future goals should include serious testing of these formulae on dry bones from modern forensics cases to truly access their usability.

It is also important to explore the implications of the race and ethnicity specific categorizations. The formulae themselves had a mixed performance when compared to the general formulae. However, future studies should include them, especially considering specific patterns emerged regarding stature estimation.

The blanket application of formulae to juvenile remains without regard to their ancestral heritage is problematic when these categories have not been tested or discussed in the literature, especially when these categorizations are widely understood to be helpful in adult formulae. This point is also important when noting how current formulae have been derived and tested – largely from the Denver Growth Study, acknowledged to be highly homogenous, and the Franklin County Collection, only slightly more diverse. Anthropologists understand the impact of secular trends on growth and development, in addition to population drift. These should be considered when formulae are produced and used – the United States is less homogeneous now than when either collection was established, limiting their usefulness to the populations from whence they came. This study will be similarly dated in time. It could be argued that oppressive social systems limit access to various resources, such as appropriately nutrient dense food, thereby explaining potential group differences. Future studies should examine links between these systems, through socioeconomic status, and juvenile growth and development.

Body mass and stature estimation formulae should be regularly updated to reflect secular trends and again, be thoughtfully applied. When these categorizations are unnecessary, they should be ignored. However, their potential usefulness cannot be determined if they are not first examined. Put simply, representation matters.

CONCLUSION

The purpose of this study was to aggregate height, weight, and femoral measurements along with demographic information for a unique, previously unexamined modern juvenile subject population originating in the United State of America. Correlating height to two femoral measurements and weight to three, linear and exponential relationships emerged, respectively. The subject population, examined as a whole, yielded highly statistically significant stature, and body mass estimation formulae. Statistical significance was largely lost when the population was subdivided into 12 month or single year age cohorts. Given the often-difficult task of pinpointing a juvenile decedent's exact age at time of death, the use of regression formulae that rely on the measurements of all juveniles included in the sample population may be advisable. However, it should be noted that this comes with a trade-off. Formulae made without regard to age have much higher SEEs limiting their usefulness to only when an observer simply has highly limited information. Additionally, age class formulae may be more statistically significant in studies with larger populations.

The statistical significance of these modern formulae were tested against predictive models already existing in field literature. In 75% of the comparisons, the formulae generated by this population more accurately estimated the dependent variable of stature, or body mass. If these formulae are to be utilized in the future, they should be applied to only the population they represent. Furthermore, formulae based on total maximum femoral length and mediolateral head breadth should be relied on, above the other formulae. Age, sex, race, and ethnicity based formulae were also generated and compared to these general formulae. No specific set of characteristics consistently outperformed the others but important patterns regarding the onset of puberty, the inclusion of certain measurements, and the compromises involved in the use of each formula emerged.

It should be noted, however, the formulae listed here are far from perfect. As it has been reiterated throughout this study, no body mass or stature formulae is universal. Therefore, the anthropological community should seek to continuously update formulae to best capture secular trends and reflect modern populations accurately.

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APPENDIX A: Medical conditions resulting in exclusion from study

Conditions A-F	Conditions F-O	Conditions O-Z
Abscess	Femoral lengthening	Osteogenesis imperfecta
Amputation	Femoral shortening	Osteomyelitis
Angulation	Fibrous dysplasia	Osteopenia
Avascular necrosis	Focal deficiency	Osteophyte
Caudal Regression Syndrome	Fracture	Osteoporosis
Congenital anomaly	Gaucher’s Disease	Osteotomy
Cortical desmoid	Genu Valgum Configuration	Periosteal reaction
Coxa Magna	Gracile	Rickets
Coxa Valga	Hardware	Scoliosis
Coxa Vera	Hemophilia	Slipped capital femoral epiphysis
Defect	Heterotopic bone	Tumor/Lesion/Mass
Deformation	Hip dysplasia	Uncovering of femoral head
Demineralization	Hip/Joint Effusion	Wheelchair bound subject
Diminished development	Hurler Syndrome	
Displacement	Impingement	
Down Syndrome	Legg-Calves-Perthes’ Disease	
Epitheliod hemangioma	McCune-Albright Disease	
Femoral anteversion	Ollier’s Disease	

APPENDIX B: Humboldt State University Protocol

Published on *IRB Proposal Submission* (https://www2.humboldt.edu/irbsub)

Home > (Working Title) Juvenile Remains: Predicting Body Mass and Stature in Modern American Populations

(Working Title) Juvenile Remains: Predicting Body Mass and Stature in Modern American Populations

IRB Number:
IRB 16-092
Coordination Data
Was this protocol registered as part of a grant submission?:
No
Proposed Start Date:
Sunday, January 1, 2017
Principal Investigator:
Student
Responsible Faculty or Staff Name:
Marissa A Ramsier
Responsible Faculty or Staff Department:
Anthropology
Responsible Faculty or Staff Email:
[redacted] [1]
Responsible Faculty or Staff Phone Number:
(707) 826-4948
CITI Training Date of Completion:
Tuesday, January 13, 2015
Student or External Name:
Erin Pinkston
Student or External Department:
Department of Anthropology
Student or External Email:
[redacted] [2]
Student or External Phone Number:
[redacted]
Qualifications:
Masters of Applied Anthropology, Humboldt State University, Arcata CA (expected May 2017)
Bachelors of Arts in Anthropology, UC Berkeley, Berkeley CA (2011) Accelerated 3 year undergraduate program of own design, 2008 – 2011 Cumulative GPA 3.449 Major GPA 3.538
Responsibilities:
Coordinate with host institution - Children's Mercy Hospital in Kansas City, MI Document pertinent personally identifying information (PIH Protect PIH in accordance with IRB and HIPAA protocols
Formulate

CITI Training Complete:
Yes
CITI Training Date of Completion:
Monday, January 26, 2015
Contact Name:
Sheena Glasgow
Email:
[redacted] [3]
Department:
Department of Anthropology
Phone Number:
[redacted]
CITI Training Complete:
Yes
CITI Training Date of Completion:
Thursday, November 10, 2016
Purpose of Project:
Graduate Research
Do you or anyone else plan on disseminating the information acquired from this project outside of the specified course classroom or the University? (Please check “yes” for dissemination if you are conducting research for a thesis that will be published on Digital Scholar.):
Yes
If Yes, please explain:
Thesis will be published via Digital Scholar. All or part of thesis will be utilized for articles/presentations disseminated via publications in professional journals and conferences.
CITI Training Complete:
Yes
CITI Training Complete:
Yes
Assurances:
Ensuring the quality and accuracy of the written materials included in the Application for Review; Ensuring Human Subjects in Research Training for all personnel who may interact with human subjects or have access to subjects' information or responses;
Supervising the conduct of research protocols submitted under their direction;
Ensuring compliance with all federal, state and local regulations, as well as Humboldt State University policies regarding the protection of human subjects in research;
Adhering to any stipulations imposed by the Humboldt State University IRB;
Ensuring that permission from outside institutions (e.g., tribes, hospitals, prisons, or schools) is obtained, if applicable; Retaining all research data, including informed consent documentation of participants, in accordance with institutional, local, state and federal regulations; Reporting to the Humboldt State University IRB immediately if there are any adverse events and/or unanticipated problems involving risks to subjects or others.

Lay Abstract:
As of September 21, 2016, the United States of America had the remains of approximately 2384 unidentified children. Accurately identifying body size (e.g., height and weight) can aid in identifying these remains. Current models for predicting the body mass and stature from juvenile skeletal remains are limiting. In order to provide this identifying information to a variety of agencies – from anthropologists to local law enforcement – predictive models need to be updated with measurements from more diverse, living populations. This study proposes to develop an improved predictive model for juvenile body mass and stature that more accurately represents modern American children by aggregating information from existing medical images of leg bones from a large, diverse population of living juveniles with known stature and body mass measurements.

Type of Data:
Secondary/Existing Data or Records

Sources for data or records:
REDcap database from Mercy Children's Hospital of Kansas City, MI

Type of Subjects:
Juveniles

Estimated Number of Subjects:
5,000

Expected Age of Subjects:
12 months old - 17 years old

Approximate total time commitment required from subjects:
0

Will subjects be Compensated?:
No

Description:
The present study seeks to improve upon a previous study (Ruff 2007), which based regression formulae on a sample of 20 individuals from an ancestrally homogeneous population – largely children of European descent, which is highly unlikely to represent the current diversity in the U.S.

Additionally, the study population largely hailed from upper-middle class families – this socioeconomic status potentially provided the subjects with unique access to nutritionally dense food, regular outdoor play, and routine healthcare. All of these factors have been shown to affect the development of the juvenile skeleton, thus the regression formulae derived from this homogeneous population may not accurately reflect the uniquely diverse population that is modern America. This is a reimagining of an “old” question with not only a new age cohort but a more nuanced approach. This study seeks to utilize a larger, more modern cohort that includes children from a variety of ancestral backgrounds and socio-economic statuses. By creating a cohort more representative of the modern population, we can produce formulae that will more accurately and precisely predict body mass and stature.

Recruitment and Selection:
This study requires images from subjects 12 months to 17 years of age, who received a radiograph or CT examination that includes an anteroposterior view of either femur as part of routine clinical at CMH between January 1, 2008 and October 1, 2016. Subjects must have been

of or between ages 12 months and 17 years of age at time of imaging. Exclusion Criteria • Those younger than 12 months of age or older than 17 years of age at time of radiograph • Those with localized anomalies affecting the femur (e.g. mass, tumor) • Those with illnesses and/or injuries affecting the individual's stature and/or body mass development (height/weight) (e.g. developmental dysplasia, Down Syndrome, dwarfism, gigantism, Legg Calve Perthes, Marfan Syndrome, metarsus adductus/femoral anteversion/tibial torsion, polio, rickets, Scheuermann's disease, scoliosis, slipped capital femoral epiphysis, spondylosis/spondylolisthesis, and tarsal coalition)

Types of Vulnerable Subjects:

Children (see Federal Guidelines, 45CFR46 subpart D [4])

If vulnerable subjects are involved, describe safeguards for each population::

As the subjects of this study are children under the age of 18, this study does rely on vulnerable subjects. Special measures will be taken by both CMH, in accordance with HIPAA law and internal policies, and principal investigators to ensure the safety and anonymity of all subjects. No personally identifying information will be collected. No contact will be made with the subject. The principal investigators will undergo HIPAA training and following HIPAA laws in addition to institutional policies in order to ensure compliance.

Documentation Type:

Waiver of Informed Consent [5]: Under certain circumstances, an IRB may approve a consent procedure which does not include, or which alters, some or all of the elements of informed consent.

Consent Process:

No images will be taken specifically for this study. This study will utilize images already existing for other medical purposes, during which consent was obtained by the medical institution. This project will utilize already-existing medical images not taken for this specific project. Collaborating medical institutions are involved in research and obtain permission for data to be used in research at the time of treatment. At the time of the images being collected, the parent/guardian of all subjects will have consented to the creation of these medical images and their sharing with researchers. The consent process for this project will therefore be with the institution, not the subjects themselves. No contact will be made with subjects.

Methods:

Utilizing the resources of CMH, a search of radiology information systems (RIS) will be conducted. Parameters will include radiology reports comprised of femurs, scanograms, and long bone radiographs performed at CMH. All reports meeting this criteria will be accessed utilizing CMH's REDcap database. Charts that do not meet with the above criteria will be removed from the study and no data will be collected. The protected healthy information (PHI) that this study intends to collect are age, gener, race, ethnicity, and femur measurements. For stature, the diaphyseal lengths and the total maximum length of the femur will be measured. Diaphyseal or inter-metaphyseal lengths of the

femura will be measured at their maximum lengths - measurements will be taken between proximal and distal ends, parallel to the diaphyses. This measurement will not include epiphyses. The total maximum length will include epiphyses. It is measured from the most distal point of the femoral medial condyle to the most proximal point of the femoral head. For body mass, the maximum superoinferior femoral head breadth and the maximum mediolateral femoral breadth will be measured. Maximum superoinferior (S-I) femoral head breadth is measured along perpendicular to the head-neck axis. Maximum mediolateral (M-L) femoral breadth is measured between the most medially and laterally projecting points on the metaphyseal surface almost perpendicular to the long axis of the femoral shaft. All data will be collected and stored in a REDcap database. Database will be password protected and only accessibly by study personnel. A master list linking MRN and study-ID numbers will be kept separate in REDcap by CMH. That master list will be destroyed at the conclusion of this study. Records generated will be an Excel spreadsheet of the data within REDcap Data will be stored on a password protected computer within a restricted access departmental folder. Only limited study personnel will be able to access it.

Benefits:

It has been estimated, conservatively, by the National Institute for Justice that the United States has approximately 40,000 unidentified remains at any time. Nationwide 4,400 unidentified remains are recovered annually. At the end of each year, 1,000 of those remains are still without names. These statistics only suggest that the number of unidentified in our country will continue to grow in the immediate future, fueling the need for law enforcement to possess improved or new tools to identify the unknown persons. Rigorously produced stature and body mass predictive models will lead to a greater number of identifications. Ultimately, the more effective predictive models are, the greater likelihood unidentified victims will be reunited with their loved ones. This study intends to close the identification gap between populations in America.

Potential Risks:

This study relies on information gathered by outside institutions from vulnerable populations. Due to the sensitive nature of the information being collected and the vulnerability of the population itself, there is a potential for subjects to be identified based on their medical information. However, this is highly unlikely given that no identifying information will be collected or reported. No personally identifying information will be collected. No contact will be made with subjects.

Risk Management Procedures:

This study seeks to minimize as many risks as possible in order to protect the identities of the subjects. Only PHI pertinent to the study will be recorded. All images will be provided with a randomly assigned code for internal identification purposes only. Database will be password protected and only accessibly by study personnel. A master list linking MRN and study-ID numbers will be kept separate in REDcap by CMH. That master list will be destroyed at the conclusion of this study.

Anonymity and Confidentiality:

The medical record of each subject will be reviewed by research personnel. Associated PHI data will be recorded in REDcap database. The master linking list will be made in REDcap. This master list will only be available to research personnel.

Data Storage, Security and Destruction:

Research data will be entered into REDcap and stored on a CMH server. Development of data entry method will be done in collaboration with Medical Information Technology in order to comply with all internal CMH and IRB protocols. CMH maintains a Microsoft Windows-based network. Its security measures included individualized log-ins on a server and log-ins are “backed up” daily. CMH servers are protected by two firewall protected Internet connections.

All data generated in REDcap will only contain information listed on data collection sheet. All data will be protected with an assigned study ID number. Database access will be limited to study personnel. A master linking list with subject study ID numbers and MRN will be kept separate from REDcap database and will only be accessible by study personnel.

Informed Consent Storage:

All informed consent will be collected by CMH prior to this study. It will be stored by CMH in accordance with HIPAA and internal protocols. No images will be taken specifically for this study. This study will utilize images already existing for other medical purposes, during which consent was obtained by the medical institution.

Supplement:

citiCompletionReport5957556.pdf [6]
CITI Training Certificate.pdf [7]
Ruff C_Body Size Prediction From Juvenile Skeletal Remains_)American Journal of Physical Anthropology_2007_133_698-716.pdf [8]
Thesis_Power Analysis_Draft 1.docx [9]

Reviewer Comments:

11/21/16 Hi Erin, Thank you for submitting your interesting application. I have just a few review points: 1. In the Purpose of Project section, I believe dissemination should be checked "yes." Please describe how you will disseminate your research, such as through Digital Scholar. 2. I do not believe you need to list the hospital staff as personnel. If they were listed as personnel, they would need to take CITI training. 3. Since you are studying secondary data, you do not need to check the boxes for informed consent and parental permission in section #7. Instead, check the box for waiver of informed consent. 4. Your description of your consent process in section #8 is excellent. It also is important that section #11 states that no identifying information will be collected or reported. Once you have answered the review points, please check the box to Notify IRB Reviewer in the Principal Investigator Review Section. Be sure to save your changes, and I will be notified. Please let me know if you have any questions. Thanks, Susan

I approve of this application.

Reviewer Data and Comments

Principal Investigator Comments:

Hi Susan, Thank you for your quick response and clear comments! I have - 1. Changed dissemination to "yes" under Purpose of Project. I have included the following: "Thesis will be published via Digital Scholar. All or part of thesis will be utilized for articles/presentations disseminated via publications in professional journals and conferences." 2. Removed the hospital staff from the Personnel section. 3. For section #7 Documentation of Consent, I have unchecked the boxes for informed and parental consent. I have checked the box for waiver of consent. 4. For section #11 Potential Risks, I have included the following: "No personally identifying information will be collected. No contact will be made with subjects." I hope these changes appropriately address Principal Investigator Review Comments your recommendations! Thank you.

Source URL: https://www2.humboldt.edu/irbsub/?q=node/1120

Links

[1] mailto:[redacted]
[2] mailto:[redacted]

[3] mailto:[redacted]
[4] http://www.hhs.gov/ohrp/humansubjects/guidance/45cfr46.html#subpartd
[5] http://www.hhs.gov/ohrp/humansubjects/guidance/45cfr46.html#46.116
[6] https://www2.humboldt.edu/irbsub/sites/default/files/citiCompletionReport5957556.pdf
[7] https://www2.humboldt.edu/irbsub/sites/default/files/CITI%20Training%20Certificate_0.pdf
[8]
https://www2.humboldt.edu/irbsub/sites/default/files/Ruff%20C_Body%20Size%20Prediction%20From%20Juvenile%20
Skeletal%20Remains_%29American%20Journal%20of%20Physical%20Anthropology_2007_133_698-716.pdf
[9] https://www2.humboldt.edu/irbsub/sites/default/files/Thesis_Power%20Analysis_Draft%201.docx

APPENDIX C: Humboldt State University Protocol Approval

707-826-5165 | irb@humboldt.edu | www.humboldt.edu/human_subjects

MEMORANDUM

Thank you for submitting your application to the Committee for the Protection of Human Subjects in Research. After reviewing your proposal I have determined that your research can be categorized as Exempt by Federal Regulation 45 CFR 46.101 (b) because of the following: cc: Faculty Adviser (if applicable)

The Exempt designation of this proposal will expire on **11/28/2017**. By Federal Regulations, all research related to this protocol must stop on the expiration date and the IRB cannot extend a protocol that is past the expiration date. In order to prevent any interruption in your research, please submit a renewal application in time for the IRB to process, review, and extend the Exempt designation (at least one month).

Important Notes:

- Any alterations to your research plan must be reviewed and designated as Exempt by the IRB prior to implementation.

-Change to survey questions

-Number of subjects

- Location of data collection,

- Any other pertinent information

- If Exempt designation is not extended prior to the expiration date, investigators must stop all research related to this proposal.
- Any adverse events or unanticipated problems involving risks to subjects or others must be reported immediately to the IRB (irb@humboldt.edu).

Your research will involve the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, and the sources are publicly available or the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

Subject: Juvenile Remains: Predicting Body Mass and Stature in Modern American Populations

11/28/2017

Institutional Review Board for the Protection of Human Subjects

To: Marissa A Ramsier

Erin Pinkston

IRB #: IRB 16-092

Institutional Review Board for the Protection of Human Subjects

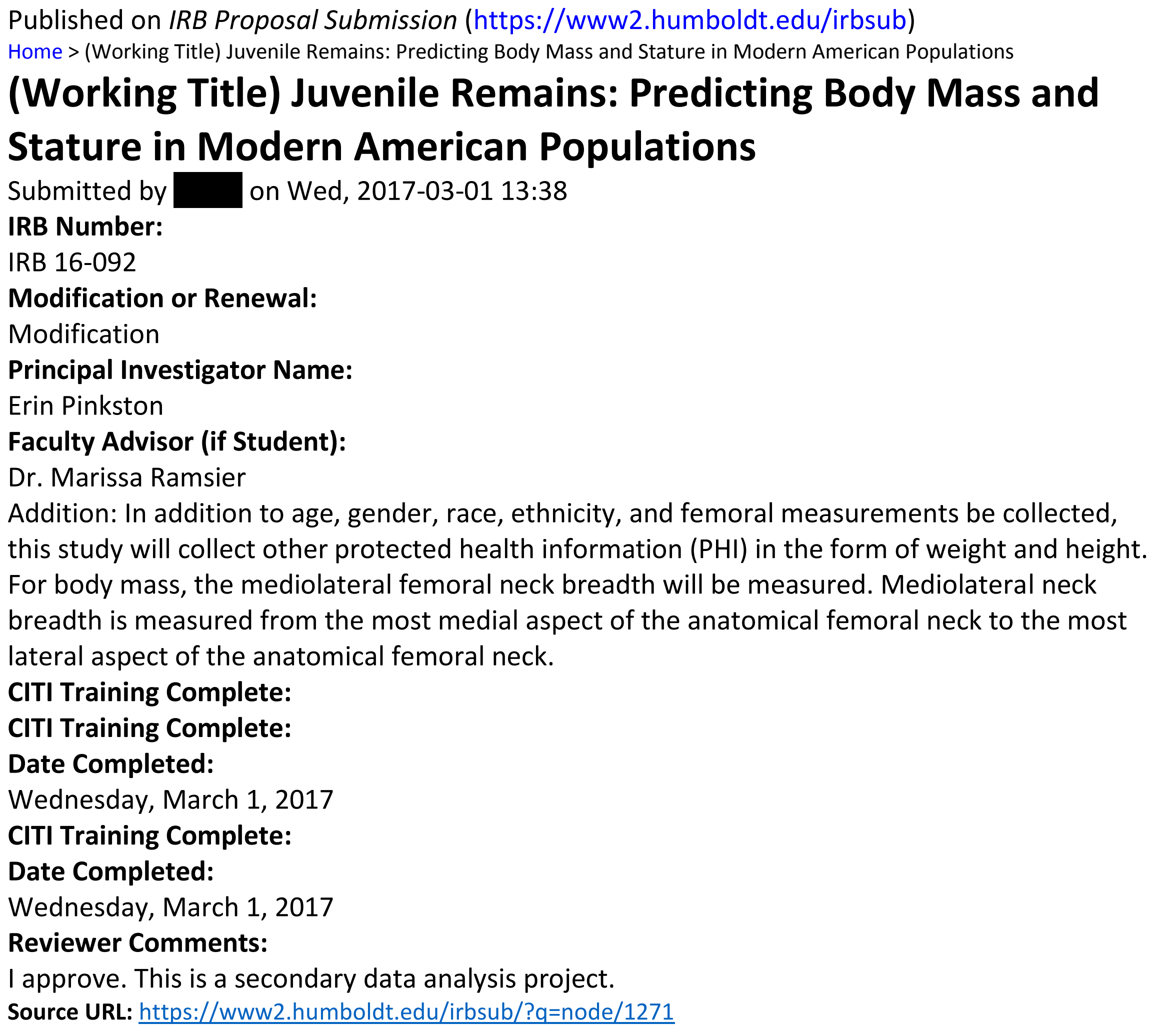
From: Susan Brater

Date: 11/29/2016

The California State University

Bakersfield • Channel Islands • Chico • Dominguez Hills • East Bay • Fresno • Fullerton • Humboldt • Long Beach • Los Angeles • Maritime Academy • Monterey Bay • Northridge • Pomona •Sacramento • San Bernardino • San Diego • San Francisco • San Jose • San Luis Obispo • San Marcos • Sonoma • Stanislaus

APPENDIX D: Humboldt State University Protocol Modification



Published on *IRB Proposal Submission* (https://www2.humboldt.edu/irbsub)

Home > (Working Title) Juvenile Remains: Predicting Body Mass and Stature in Modern American Populations

(Working Title) Juvenile Remains: Predicting Body Mass and Stature in Modern American Populations

Submitted by [redacted] on Wed, 2017-03-01 13:38

IRB Number:

IRB 16-092

Modification or Renewal:

Modification

Principal Investigator Name:

Erin Pinkston

Faculty Advisor (if Student):

Dr. Marissa Ramsier

Addition: In addition to age, gender, race, ethnicity, and femoral measurements be collected, this study will collect other protected health information (PHI) in the form of weight and height. For body mass, the mediolateral femoral neck breadth will be measured. Mediolateral neck breadth is measured from the most medial aspect of the anatomical femoral neck to the most lateral aspect of the anatomical femoral neck.

CITI Training Complete:

CITI Training Complete:

Date Completed:

Wednesday, March 1, 2017

CITI Training Complete:

Date Completed:

Wednesday, March 1, 2017

Reviewer Comments:

I approve. This is a secondary data analysis project.

Source URL: https://www2.humboldt.edu/irbsub/?q=node/1271

APPENDIX E: Humboldt State University Protocol Modification Approval

707-826-5165 | irb@humboldt.edu | www.humboldt.edu/human_subjects

MEMORANDUM

Thank you for submitting your application to the Committee for the Protection of Human Subjects in Research. After reviewing your proposal and revisions, I have determined that your research can be categorized as Exempt by Federal Regulation 45 CFR 46.101 (b) because of the following: cc: Faculty Adviser (if applicable)

The Exempt designation of this proposal will expire on **11/28/2017**. By Federal Regulations, all research related to this protocol must stop on the expiration date and the IRB cannot extend a protocol that is past the expiration date. In order to prevent any interruption in your research, please submit a renewal application in time for the IRB to process, review, and extend the Exempt designation (at least one month).

Important Notes:

• Any alterations to your research plan must be reviewed and designated as Exempt by the IRB prior to implementation.

-Change to survey questions

-Number of subjects

- Location of data collection,

- Any other pertinent information

• If Exempt designation is not extended prior to the expiration date, investigators must stop all research related to this proposal.

• Any adverse events or unanticipated problems involving risks to subjects or others must be reported immediately to the IRB (irb@humboldt.edu).

Your research will involve the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, and the sources are publicly available or the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

Subject: Juvenile Remains: Predicting Body Mass and Stature in Modern American Populations

11/28/2017

Institutional Review Board for the Protection of Human Subjects

To: Marissa A Ramsier

Erin Pinkston

IRB #: IRB 16-092

Institutional Review Board for the Protection of Human Subjects

From: Susan Brater

Date: 3/1/2017

The California State University

Bakersfield • Channel Islands • Chico • Dominguez Hills • East Bay • Fresno • Fullerton • Humboldt • Long Beach • Los Angeles • Maritime Academy • Monterey Bay • Northridge • Pomona •Sacramento • San Bernardino • San Diego • San Francisco • San Jose • San Luis Obispo • San Marcos • Sonoma • Stanislaus

APPENDIX F: Children’s Mercy Hospital Protocol

Juvenile Remains: Predicting Body Mass and Stature in Modern American Populations

Principal Investigator: Erin Pinkston Humboldt State University Masters Candidate, Applied Anthropology [redacted] **Co-Investigators:** Sherwin Chan, MD PhD The Children’s Mercy Hospital Assistant Professor Department of Radiology [redacted] Sheena Glasgow Humboldt State University Undergraduate, Anthropology [redacted]	**Research Personnel:** Amie Robinson, BSRT(R)(MR) The Children’s Mercy Hospital Research Coordinator Department of Radiology [redacted]

Study Site(s): Children's Mercy Hospital

Protocol Version: *(1.0)* **Protocol Date:** 10-11-2016

1. STUDY OBJECTIVES/HYPOTHESIS

To improve upon current models for estimating the stature and body mass of juveniles based on dimensions of the femur, to aid in the identification of juvenile skeletal remains.

PRIMARY OBJECTIVE

The primary objective of this research is to create a statistically significant formula estimating juvenile body mass and stature from femora. This formula will be based on measurements taken from existing radiographic images.

SECONDARY OBJECTIVE(S):

The secondary objective of this research is to create body mass and stature formulae for juvenile remains that more accurately and precisely represent the modern population of American children.

BACKGROUND

The present study seeks to improve upon a previous study (Ruff 2007), which based regression formulae on a sample of 20 individuals from an ancestrally homogeneous population – largely children of European descent, which is highly unlikely to represent the current diversity in the U.S. Additionally, the study population largely hailed from upper-middle class families. This socio-economic status potentially provided the subjects with unique access to nutritionally dense food, regular outdoor play, and routine healthcare. All of these factors have been shown to affect the development of the juvenile skeleton, thus the regression formulae derived from this homogeneous population may not accurately reflect the uniquely diverse population that is modern America.

This is a reimagining of an “old” question with not only a new age cohort but a more nuanced approach. This study seeks to utilize a larger, more modern cohort that includes children from a variety of ancestral backgrounds and socio-economic statuses. By creating a cohort more representative of the modern population, we can produce a formulae that will more accurately and precisely predict their body mass and stature.

2. RATIONALE

It has been estimated, conservatively, by the National Institute for Justice that the U.S. has approximately 40,000 unidentified remains of adults and juveniles at any time. Nationwide 4,400 unidentified remains are recovered annually; at the end of each year, 1,000 of those remains are still without names. These statistics only suggest that the number of unidentified in our country will continue to grow in the immediate future, fueling the need for law enforcement to possess improved or new tools to identify the unknown persons. Rigorously produced stature and body mass predictive models will lead to a greater number of identifications.

STUDY DESIGN

This is a retrospective study utilizing radiographs and clinical data previously obtained as part of routine clinical at CMH.

3. TARGET STUDY POPULATION SPECIFICS

A retrospective chart review of subjects 12 months to 17 years of age, who received a radiograph or CT examination that includes a anteroposterior view of their femur as part of routine clinical at CMH between 2008and 10/1/2016

Inclusion Criteria

Subject's ages 12 months to 17 years of age at time of imaging

Exclusion Criteria

- Those younger than 12 months of age or older than 17 years of age at time of radiograph
- Those with localized anomalies affecting the femur (e.g. mass, tumor)
- Those with illnesses and/or injuries affecting the individual's stature and/or body mass development (height/weight) (e.g. genetic or metabolic anomaly affecting bones)

4. DATA COLLECTION

Data Collection Procedures

We will search radiology information systems (RIS) database of radiology reports to find all femur, scanogram and long bone radiographs performed at our institution. Charts meeting inclusion criteria will have data recorded in CMH REDcap database. Charts not meeting inclusion criteria will be removed from the study and no data will be recorded.

Records to be kept

Protected health information (PHI) to be collected for the purpose of this study alone will include: age, gender, race, ethnicity, femur measurements. For stature, the diaphyseal lengths and the total maximum length of the femur will be measured. Diaphyseal or inter-metaphyseal lengths of the femura will be measured at their maximum lengths - measurements will be taken between proximal and distal ends, parallel to the diaphyses. This measurement will not include epiphyses. The total maximum length will include epiphyses. It is measured from the most distal point of the femoral medial condyle to the most proximal point of the femoral head. For body mass, the maximum superoinferior femoral head breadth and the maximum mediolateral femoral breadth will be measured. Maximum superoinferior (S-I) femoral head breadth is measured along perpendicular to the head-neck axis. Maximum mediolateral (M-L) femoral breadth is measured between the most medially and laterally projecting points on the metaphyseal surface almost perpendicular to the long axis of the femoral shaft. All data will be collected and kept in a password protected database (REDcap) that only study personnel will have access to. A master linking list between MRN and study-ID numbers will be kept separately in REDcap and will be destroyed upon completion of the study. The research record generated will consist of an excel spreadsheet from the data dictionary within REDcap. Security measures include: storage of the data on a password protected computer in a restricted access departmental folder limited only to identified study personnel.

Secure Storage of Data

Data will be manually entered into REDcap and stored on the hospital server. Development of data entry record will occur in collaboration with Medical Information Technology to ensure compliance and completeness. The Children's Mercy Hospital (CMH) Windows-based network is configured with the security of an individualized log in on a server that is backed up daily. Resources provide full support for electronic data collection, storage, analysis and exchange. The network is maintained by the Hospital Information Services professional staff. CMH has two firewall protected Internet connections that allow transmission of large data and graphics files between CMH investigators and collaborators with I-2 connections. CMH has secure transport appliances that use SSH, SFTP, and FTPS protocols to allow researchers to transmit and receive large datasets manually or automatically.

The research record generated in REDcap will only contain data points listed in data collection sheet and assigned by study ID number. REDcap access limited to CMH study personnel. A master linking list with subject study ID number and MRN will be maintained in a separate REDcap form within the project that only study personnel will have access to.

5. STUDY DURATION/STUDY TIMELINE

Stage 1, patient accrual –

According to a power analysis, the present study should include a minimum of 15 observations (femora) for each age class (year) from ages 1-17 (totaling 255 observations) in order to produce a statistically significant predictive model, assuming age is the only category. Introducing more categories, such as sex, will increase the number observations required. An ideal minimum of 1275 observations will be made based on age categories (1-17) and ancestry categories (European, African, Asian, Native American, other).

Approximately 5,000 radiographs will be measured. Training to appropriately navigate institutional software will take one and half work weeks (60 hours). Afterward, it is estimated another full work week will be required to complete the measurements, assuming that the software can produce a measurement per minute. Overall, the project should take just over two and half work weeks (100+ hours).

Stage 2, data analysis –

Stage 3, grant applications-
Projected start date is upon IRB approval.
Total length of time:

6. STATISTICAL CONSIDERATIONS

General Design Issues

A radiographic enlargement correction will also be applied to data as appropriate. Utilizing the measurements, the principal investigators will perform a least squares regression analysis to produce formulae to estimate stature and body mass from femoral length.

Data Analyses

A least square regression analysis will be utilized, with statistical significance set at p<0.05.

7. HUMAN SUBJECTS

Institutional Review Board (IRB) Review and Informed Consent:

This protocol, and any subsequent modifications, will be reviewed and approved by the Pediatric IRB at The Children's Mercy Hospital & Clinics.

Subject Confidentiality

Each subject's medical record will be reviewed by research staff and data entered into the research record. A master linking list will be maintained in the REDCap database and this list will only be visible to study personnel.

Study Modification/Discontinuation

The study may be modified or discontinued at any time by the IRB or other Government agencies as part of their duties to ensure that research subjects are protected.

8. PUBLICATION OF RESEARCH FINDINGS

This research would ideally be published in a journal with an emphasis on forensic science or physical anthropology. The Journal of Forensic Science or the Journal of Physical Anthropology are preferable choices. This research would also be presented at the American Association of Physical Anthropologists annual conference.

Journal of Forensic Science – impact factor of 1.160 for 2014
Journal of Physical Anthropology – impact factor of 2.824 for 2011

9. REFERENCES

Ruff, Christopher. "Body Size Prediction from Juvenile Skeletal Remains." American Journal of Physical Anthropology 133.1 (2007): 698-716.

APPENDIX G: REDCap Database Master List

Confidential

Juvenille Remains
Page 1 of 3

Master List

Study ID ______________________________

MRN: ______________________________

03/24/2017 10:11am

www.projectredcap.org

Data Collection Form

Demographic Information

Age (years): ____________________________

Gender:
○ Male
○ Female
○ Unknown

Race:
☐ American Indian/Alaska Native
☐ Asian/East Asian/Central Asia
☐ Native Hawaiian or Other Pacific Islander
☐ Black or African American
☐ White
☐ Multiracial
☐ Other
☐ Unknown/Not Reported

If Other, Please Define: ____________________________

Ethnicity:
○ Non-Hispanic
○ Hispanic
○ Unknown/Not Reported

Height (cm): ____________________________

Weight (kg): ____________________________

Relevant Medical History

Does Patient Have History of Femur Fractures?
○ Yes
○ No
○ Unknown

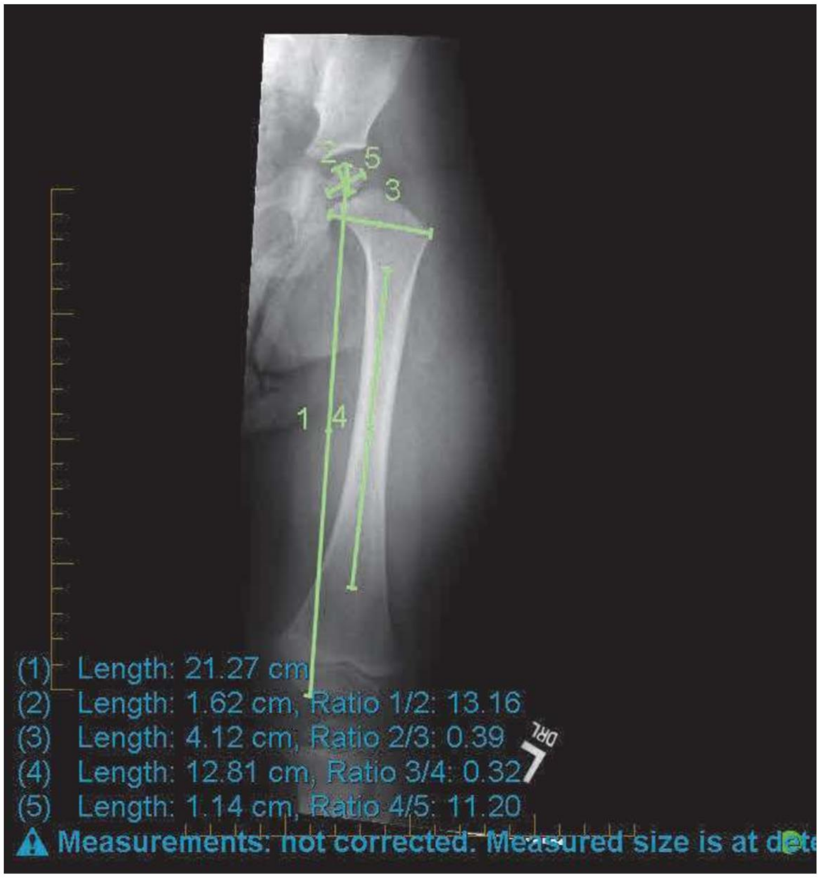
If Yes, Side of Fracture:
☐ Right
☐ Left
☐ Bilateral

Age at time of Fracture: ____________________________

Did Patient Require Surgery?
○ Yes
○ No

Imaging Measurements

Femoral Measurements:



(1) Length: 21.27 cm
(2) Length: 1.62 cm, Ratio 1/2: 13.16
(3) Length: 4.12 cm, Ratio 2/3: 0.39
(4) Length: 12.81 cm, Ratio 3/4: 0.32
(5) Length: 1.14 cm, Ratio 4/5: 11.20
⚠ Measurements: not corrected. Measured size is at d

1) Total maximum length (cm) ____________________

2) Maximum superoinferior (SI) femoral head breadth (cm) ____________________

3) Maximum mediolateral (ML) femoral breadth (cm) ____________________

4) Diaphyseal length (cm) ____________________

5) Maximum mediolateral (ML) femoral head breadth (cm) ____________________

APPENDIX H: Raw Data

Available upon request.