Method For Analyzing Juvenile Growth Across Populations

A Senior Honors Thesis

Presented in Partial Fulfillment of the Requirements for Graduation *with research distinction* in
Anthropology in the Undergraduate Colleges of The Ohio State University

by

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Table of Contents

Abstract

Comparing growth data across populations is one way to assess health differences among people. However, judging these populations based on raw data does not accurately reflect differences until data is standardized. A detailed analysis using population-independent methods that discard source sample problems and normalize the results is the best method for comparing growth data. Here, I present a demonstration of this method using data collected from four prehistoric Ohio Valley sites: SunWatch, Danbury, Buffalo, and Pearson Village. This paper presents a compilation of adult and juvenile skeletal characteristics of an internally-consistent analysis that produced a set of statistical data illustrating continuity between the growth of prehistoric Native American juveniles and modern white juveniles of European descent.

Introduction

The estimation of body size is useful both in archaeological and forensic contexts. Body size estimation of juveniles in any population is fundamental to reconstructing the environment of prehistoric people. Health is a dynamic relationship between genetics, culture, and subsistence. The study of subadults is critical in understanding this environment-population interaction because the early period of life has greater nutritional demands and susceptibility to disease. Paleodemographic studies that employ information from subadults in the archaeological record can potentially clarify the interaction between a population and its environment, but are limited by a need for accurate age-at-death estimation of juveniles (Cardoso, 2007).

This study examines the technique of correlating both dental and skeletal maturation rates of four pooled prehistoric Native American populations and provides an internally-consistent report on the developmental stages and maturation rates from both an archaeological and biological perspective. This research will produce a comparison of dental stage and associated skeletal age for prehistoric Native American juveniles and provide insight for paleodemographic research and contribute to our understanding of environmental influence on skeleton maturity and the assessment of general evolutionary trends in human growth and development.

Literature Review

Body mass estimation has been a crucial element in studies of paleontological and archaeological data. Auerbach and Ruff (2004) analyzed this technique in a study of over 1000 Holocene skeletons from various locations. To preserve the integrity of known data, unsexed skeletons were excluded. Formulae derived from sex and population means calculated four body mass estimates for each skeleton. Of the two general subtypes for estimating body mass from skeletons, the mechanical methods employed here rely on the relationship between stature and weight-bearing mechanisms (2004). The authors emphasize that the use of femoral head diameter is highly desirable for its frequency in the skeletal record, ease of measurement, and reproducibility. Results of their study demonstrated a regular pattern of differences between the sexes that carried across closely related groups (Auerbach and Ruff, 2004). This suggests that similar biological variation between the sexes within many populations (2004). Differences that were observed possibly originated from the samples that produced the formulas for body mass, but there was a strong observable correspondence among Holocene samples in general (2004). One of fault with this study was the poor performance of estimating stature in skeletons that fell into the statistical extremes. However, according to the authors, the use of several equations and averaging the results indicated higher accuracy when data does not fall in the extremes (Auerbach and Ruff, 2004).

Stature has also been examined recently with respect to the Fully method equation for estimating stature from skeletal elements. This equation calculates approximate stature by compensating for the flesh that remains lack. A multitude of factors influence the dynamic nature of population osteometrics. Diet can restrict cultural groups to eating certain products, modes of subsistence can affect how much the ground yields, and social hierarchy may restrict access to resources and expose one to particular diseases. All of these are indicated by the mean stature of a group. Similarly, stature indicates an evolution of physique, any degree of sexual dimorphism within a population, the nutritional status of a particular group in time, and overall health (Sciulli and Hetland, 2007). Prior to Sciulli and Hetland’s (2007) study samples of Northeast Woodland Native Americans around the Ohio River Valley area, indicated that across the Northeastern Woodlands, skeletal proportions were comparable (2007). However, the common methods of estimating stature for Ohio River Valley populations were inconsistent because the origins of the model populations were East Asian and Central American. While these samples may have had similar total stature, they did not have a similar ratio of tibia length to femur length (2007). Samples in this study were derived from prehistoric populations ranging from west-central Ohio to north-western Ohio. Individuals were included who shared mortuary features and close degrees of biological variation, producing a population sample which was analyzed to provide a revision of the Fully method equation for Native American standards (2007).

The exploration of the interaction between populations and environments is critical to understanding and reconstructing ancient ways of life. The subset most sensitive to environmental conditions is juveniles, which makes them indispensable to the study of population and environment relationships (Sciulli, 2007). The developing dentition provide excellent data on maturation, and can provide a limited age range or age estimate for any juvenile with samples. The timing of dental formation is polygenic; it is influenced by nutrition and environment, but also genetic frequencies (2007). Thus, dental formation provides a health marker and a development marker.

Consequently, the relative maturity of juveniles within a population can be used as an independent marker for age estimation (2007). Seriation of dental samples provides an internally-consistent and population-specific set of developmental milestones (2007). Sciulli (2007) scored the dental stage of 581 juveniles from eight prehistoric populations using Moorree's method. Scored teeth were seriated from least to most mature, establishing parameters for dental stages. Native American teeth were shown to mature at a faster rate than European populations, leading to bias in utilizing European standards (Sciulli, 2007). Similarly, as Sciulli (2007) points out, seriation alleviates many untestable assumptions that accompany biological and anthropological studies, namely that all populations mature in the same manner and pace.

Ruff's (2007) study of developmental radiographs from the Denver population compiled skeletal data from twenty juveniles across their maturation. Because the proportions of skeletal measurement to body mass vary throughout the maturation process, Ruff used the Denver data to produce equations within discrete age intervals (Ruff, 2007). It must be noted that individuals were marked on half-years. Thus, making the equation for estimating body mass for someone aged three would work for someone between the ages of 2.5 to 3.5 years. Juveniles do not begin to deviate with respect to sex markers until later maturation and sex is difficult to establish until complete maturation, making it necessary to pool individuals in Ruff's work (2007). Of all equations generated from juvenile measurements, Ruff found the least amount of predictive error in equations utilizing the femur and tibia. Though not all age ranges were sufficiently encompassed in discrete equations, the femur and tibia combination was most consistent (2007).

The significance of this study, however, must be balanced with its limitation of generalizability. The small sample size does not encompass all variance in limb proportions, which could explain differences between populations (2007).

Materials and Methods

This study compiled the postcranial metrics of 317 adults and 420 subadults from four prehistoric Ohio populations: Buffalo, SunWatch, Pearson Village, and Danbury. Buffalo is a Proto-historic (400-200 B.P.) Fort Ancient culture site and is located on the border of Ohio in present day Putnam County, West Virginia. SunWatch, also a Fort Ancient site, is located in Dayton, Ohio and was occupied from approximately 700 to 800 BP (DeAloia 2004, Sciulli 2008, personal communication). Pearson Village near Sandusky County, Ohio is an Early Late Prehistoric seasonal settlement of the Sandusky tradition (1000 to 400 B.P.) and is most historically related to the Central Algonquian Native American tribe (Steckel and Rose, chap. 15, p. 446). The Danbury site is located on Sandusky Bay in Ottawa County, Ohio. Danbury contained burials from a wide range of periods from Archaic (6,000 to 3,000 B.P.) to Early Woodland (3,000 to 11,000 B.P.) (Redmond 2007).

The demographic data and post-cranial measurements of each individual were compiled into a database and divided into adults and juveniles. Dental remains had been previously assessed for their maturity, seriated in order from least to most mature, and then reunited to respective skeletal remains. Adult samples were similarly analyzed then combined with juvenile data and assessed for multiple stature and mass estimates, which were averaged for highest accuracy.

Three software programs were utilized to maintain consistency and avoid human error. Measurements were recorded in Microsoft Excel 2007 and included maximum femoral length, maximum tibia length, maximum diameter of the femoral head, maximum width of the distal femur metaphysis for juveniles, and foot height. Various research studies have generated stature and body mass formulas for samples with determinable sex and ancestry as well as no determinable sex or ancestry. All formulas possible were applied to obtain the most accurate estimate. Stature and mass equations were coded into MATLAB R2006B Version 7.3.0.267. Eighteen formulas for stature were applied to the adult data, which were applied by computer software according to formula requirements (See Table 1). Five equations for body mass were applied to adult data (See Table 2). Juvenile stature was estimated using nineteen age-specific formulas (See Table 4). Twenty-one formulas were utilized to estimate juvenile body mass (See Table 3). All juvenile data was then analyzed in SAS 9.1 by creating a model with respect to age or stage which included the twenty-fifth and seventy-fifth percentile ranges. For future comparison to other populations, all juvenile tibia and femur lengths were standardized by dividing data by the average adult femur and tibia lengths (See Table 7). Graphical displays also illustrated the relationship between stage and age to long bone achievements.

Results

Calculations demonstrated a clear relationship between long bone length with stage, age, and percent of attained growth. The appendix contains a table for select long bone growth equations, and their respective velocity and acceleration. Twenty-fifth and seventy-fifth percentiles were also created from a model with a ninety-five percent confidence interval. For every value entered in a bone-specific equation, the reported answer should be within the bounds of the set intervals ninety-five percent of the time (See Table 5). There is a clear number of early juveniles whose long bone lengths are near the twenty-fifth percentile, as well as several later individuals who near the seventy-fifth percentiles (See Figure 3, and 7). Standardized data present a curvilinear line from birth through stage sixteen and age eighteen, at which point individuals had reached 100% of their adult long bone length. Clear results are not available for femur head diameters, as these were not populous enough to generate statistics.

Discussion

The data show a strong tendency for similar growth patterns. The F-value is the amount of variability in the data that can be explained by the software model. If the F-value was one, the model would not explain any variation in the data. An F-value of 1,000 would indicate that the software model accounts for a significant amount of variation in the data. Computer generated models had F-values higher than 500 for eleven calculations. F-values lower than 500 were generated for the following comparisons: mass for stage, mass for age, femoral distal metaphysis for age, and stature for mass. A lack of sufficient data can account for the relative weakness of these models.

Figure 7 illustrates a classic example of mortality bias found in cross-sectional studies. An abundance of below-average data in early stages coupled with above-average data in later stages can be explained by the cause of death in these individuals. Younger children were most likely affected by pathology and under- or malnutrition, leading to stunted growth and wasting. Older individuals who survived the pathology of childhood were more likely to die of acute situations, such as an accident or a fall (Sciulli 2008, personal communication). The mortality bias affects the generated growth models because the youngest data may not be representative of that population and bring the overall model lower. Long bones show a rapid growth rate from birth to two years which tapers slowly and gradually until maturation.

This is a demonstration that the data cannot be completely biased as growth is generally more rapid during this time than in later years. Analytically, the model produced from each data subset provides valuable information about growth. The natural log equation estimates the amount of growth attained for an age or stage in millimeters. The first derivative of the model provides the velocity or rate of growth at an age or stage. The second derivative of the model provides the acceleration of growth at an age or stage. The acceleration indicates the change in rate of growth, or whether an individual is slowing down, speeding up, or has stopped growth altogether. Each of these numbers, if attained from sample populations that imitated this method, would be ideal for cross-population comparison. The significance of this study is that an imposition of growth equations for the Denver Growth Study compiled in a similar manner onto this data was found to be comparable to this study's finds (See Figures 8, 9, 10, 11, Sciulli 2008, personal communication).

Problems and Limitations

Problems and limitations of this study arise from many sources. The analysis of dental remains may have been affected by preservation bias and/or the mineralization of samples. If teeth were lost because of harsh soil conditions, or were poorly mineralized during life and dissolved in the ground, there may be a preservation bias in the archaeological record (Sciulli 2007). Also, though stature estimation formulae were utilized from a previous study establishing the similarities in stature of many Ohio Valley Native Americans, the equations for body mass published by Ruff were derived from a different sample population (Ruff 2007). Also, Ruff's study excluded pathologic individuals, while this study did not. In juveniles, the samples for body mass estimation from Ruff were derived from a small sample of twenty children (2007). Although they were representative of the modern population of the time, it cannot be said for all prehistoric Native Americans. Equations were also reported to change significance with the age of the subject. At age fifteen, Ruff reported that no equation reached statistical significance

(2007). He attributed this to the fluctuation in weight gains and losses of teenagers, but the same cannot be said for this sample (2007).

Similarly, the differential timing in growth among pubescent individuals may affect the accuracy of equations in predicting body mass (2007). Because females mature earlier and gain weight sooner, equations may underestimate early pubescent female body mass. For males, the reverse may be true in that body mass is overestimated for younger pubescent individuals and underestimated for later pubescent individuals. Also, the relationship between body mass and the distal femoral metaphysis weakened even though the metaphysis continued to grow (2007).

Furthermore, there is an overarching mortality bias in the data. The sample utilized here comprised of dead children, who obviously never reached adulthood. Those who did not reach adulthood did not do so for a number of reasons, and cannot be assumed as representative of the population. Individuals who did not reach an adult stature or body mass may not be representative of the adults who did once have juvenile stature and body mass. Moreover, the same assumptions that make this study extremely accurate and consistent also prevent its use as a universal application. The data contained herein is for use in comparing juvenile growth across populations and should not be extrapolated beyond its parameters, especially to modern people. However, the method of analysis should be fully replicated to standardize research in order to accurately assess differences between populations.

Conclusion

The ideal method of assessing the health of a population through the study of subadults is made possible through skeletal data that has been standardized. There is a long process of collecting data to create an internally-consistent sample with its own specific developmental stages which are statistically analyzed. The resulting growth equations are the ideal data for evaluating different populations. In the future this method could be useful for evaluating differences between prehistoric groups, between modern groups, and differences in a single population over time.

Acknowledgements

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Appendix

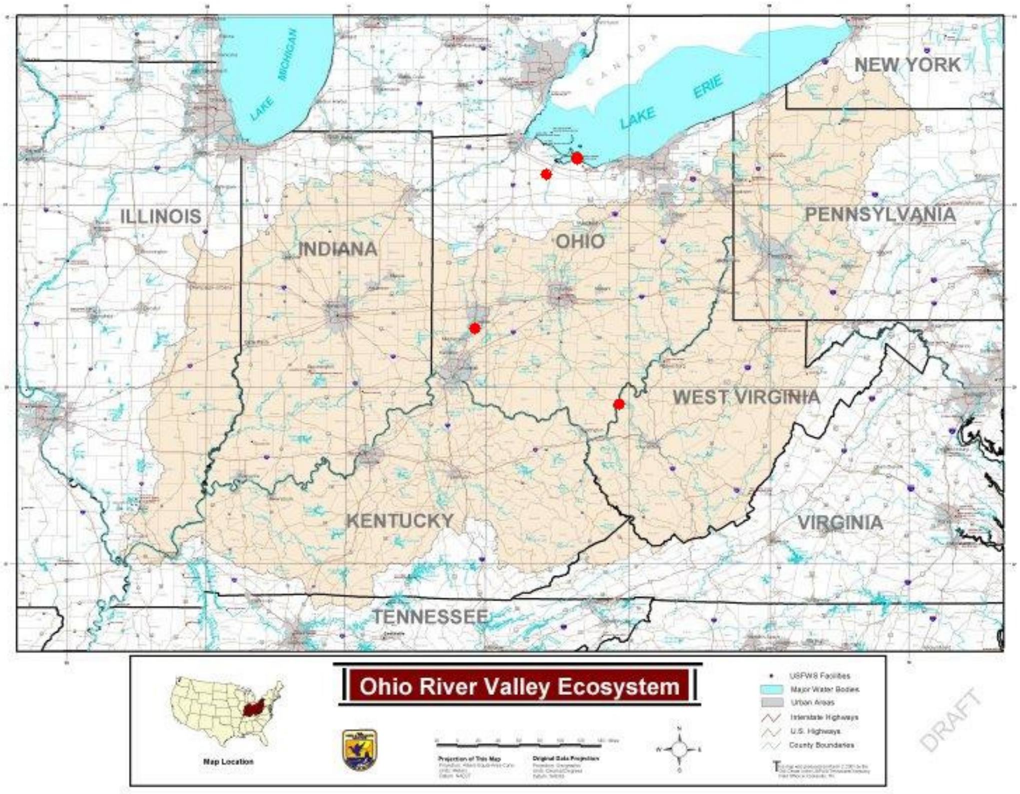

Figure 1- Map of Ohio Showing Four Burial Sites

From Left Clockwise: SunWatch of Dayton, Ohio, Pearson Village near Sandusky, Ohio, Danbury, Ohio, and Buffalo, West Virginia.

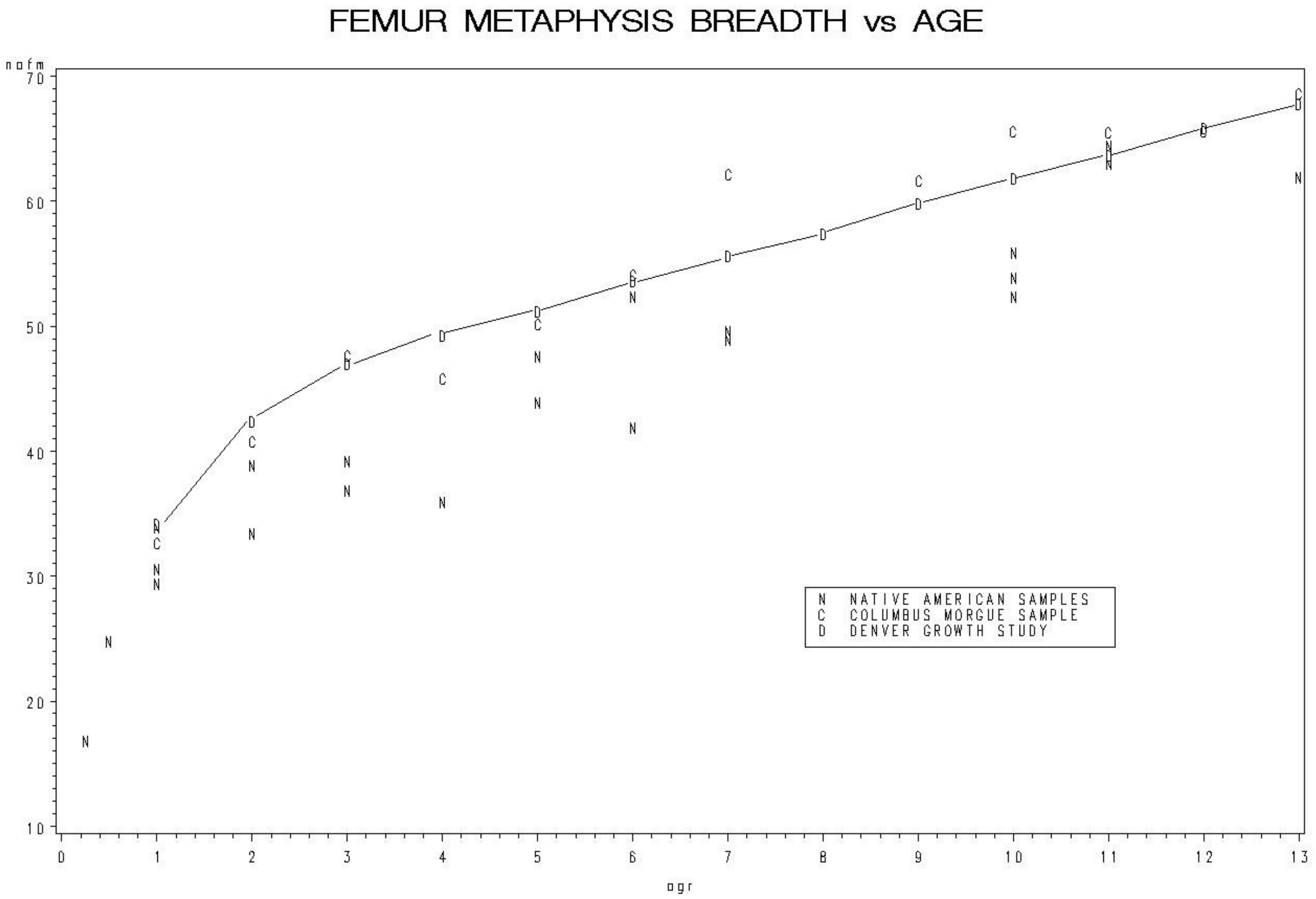

Figure 2 – Metaphysis breadth of all Native American samples compared to modern samples

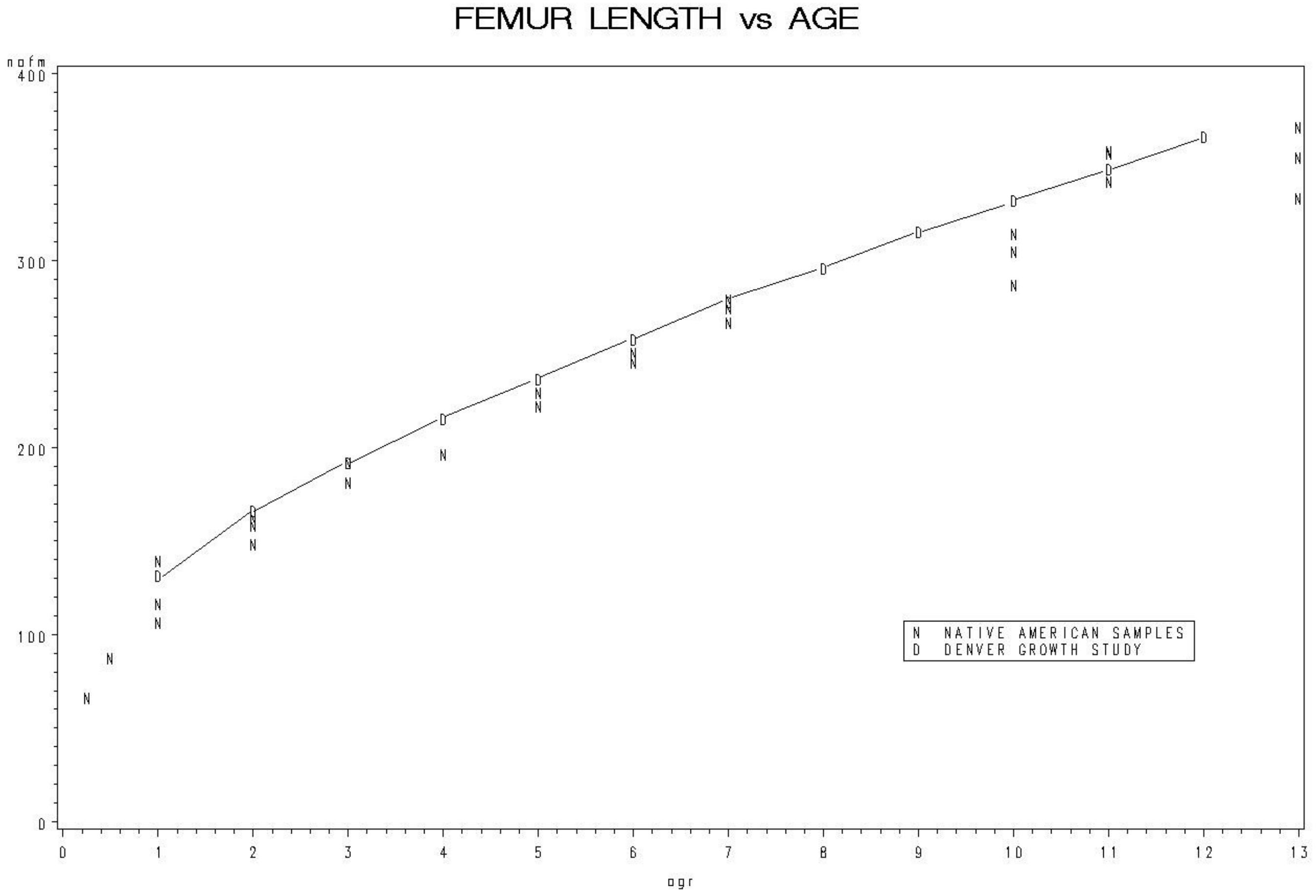

Figure 3 – Femur Lengths of all Native American samples compared to modern sample

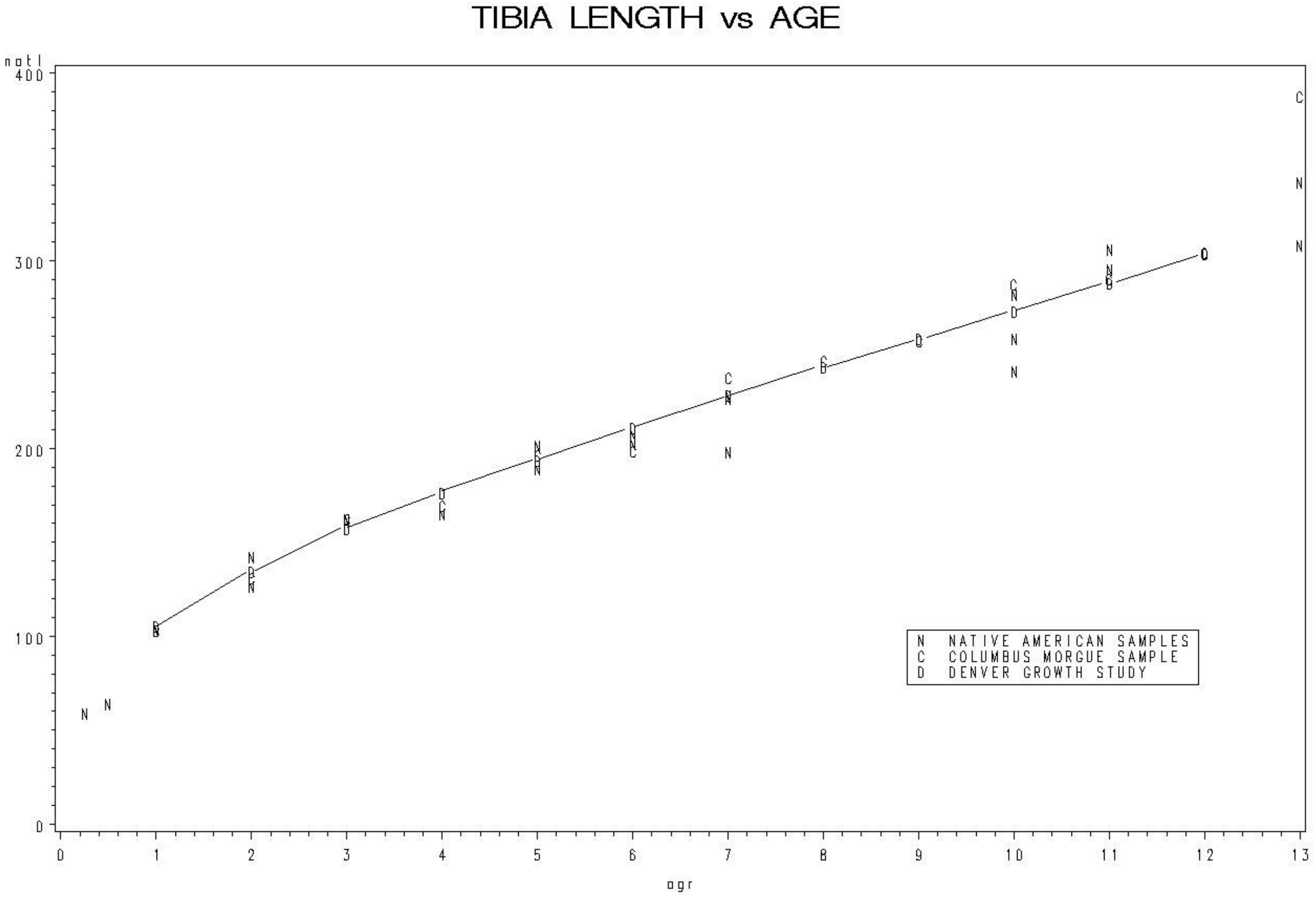

Figure 4 – Tibia Lengths of all Native American samples compared to modern samples

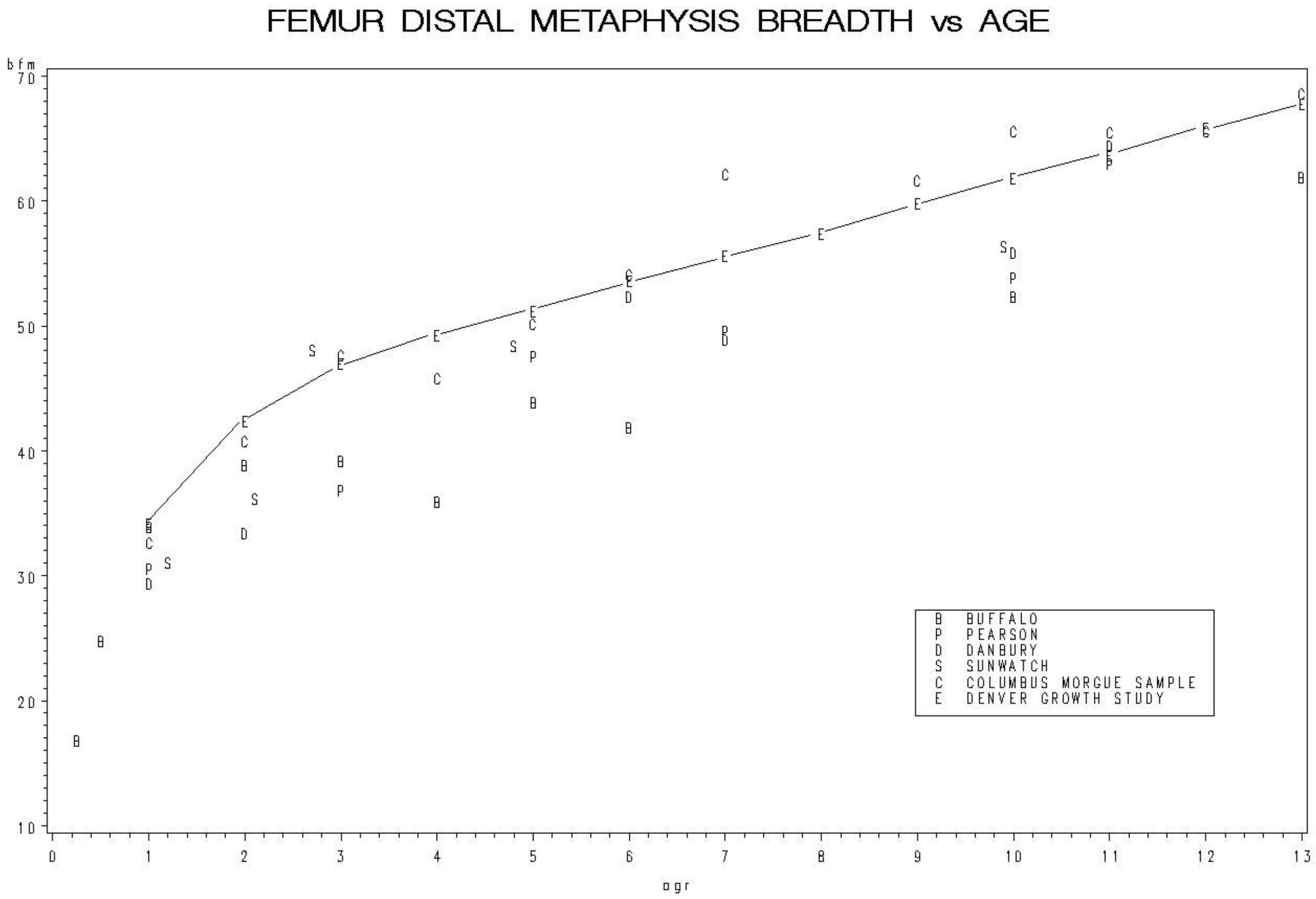

Figure 5 – Metaphysis breadths of separate Native American samples and modern samples

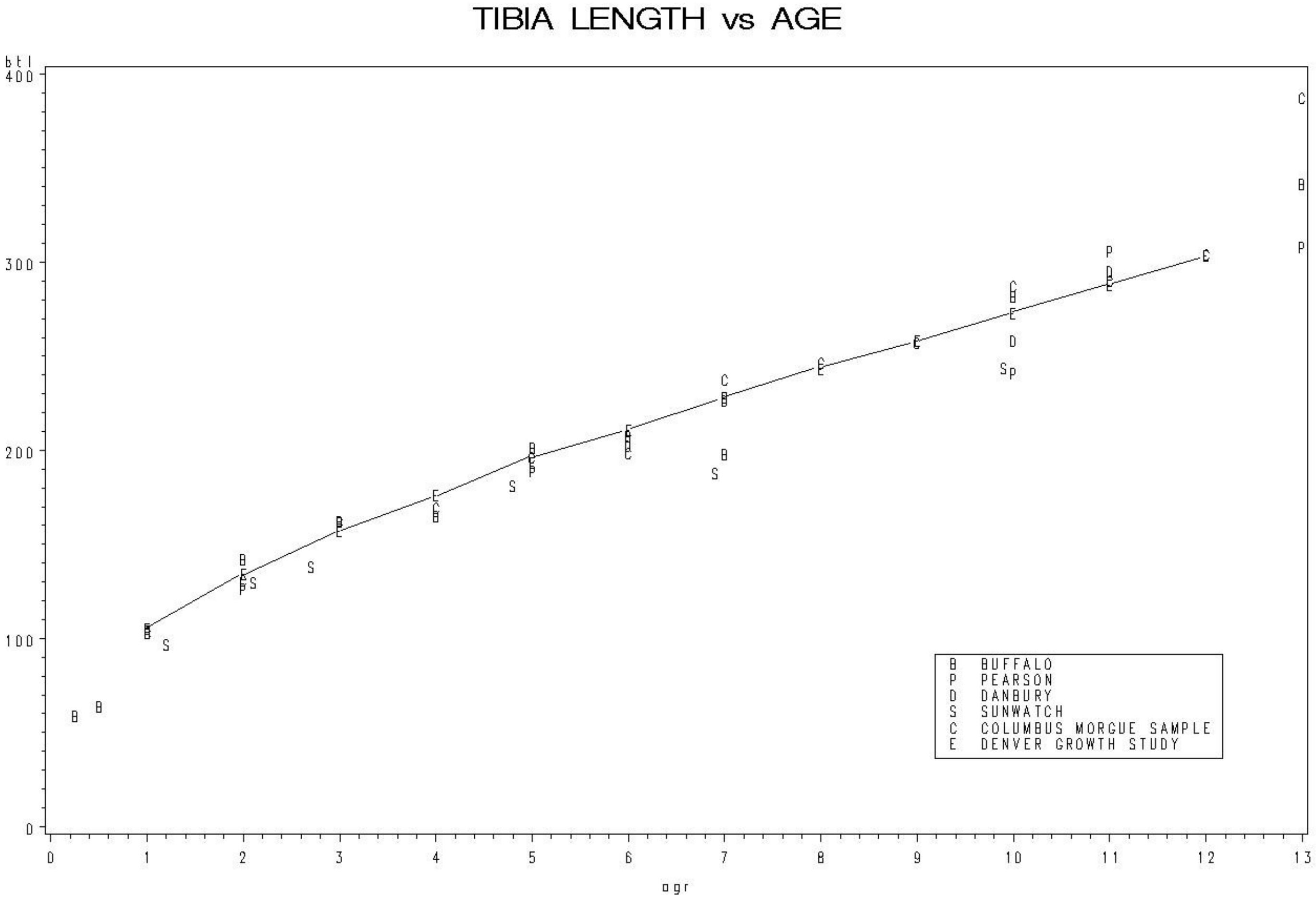

Figure 6 – Tibia lengths of separate Native American samples and modern sampls

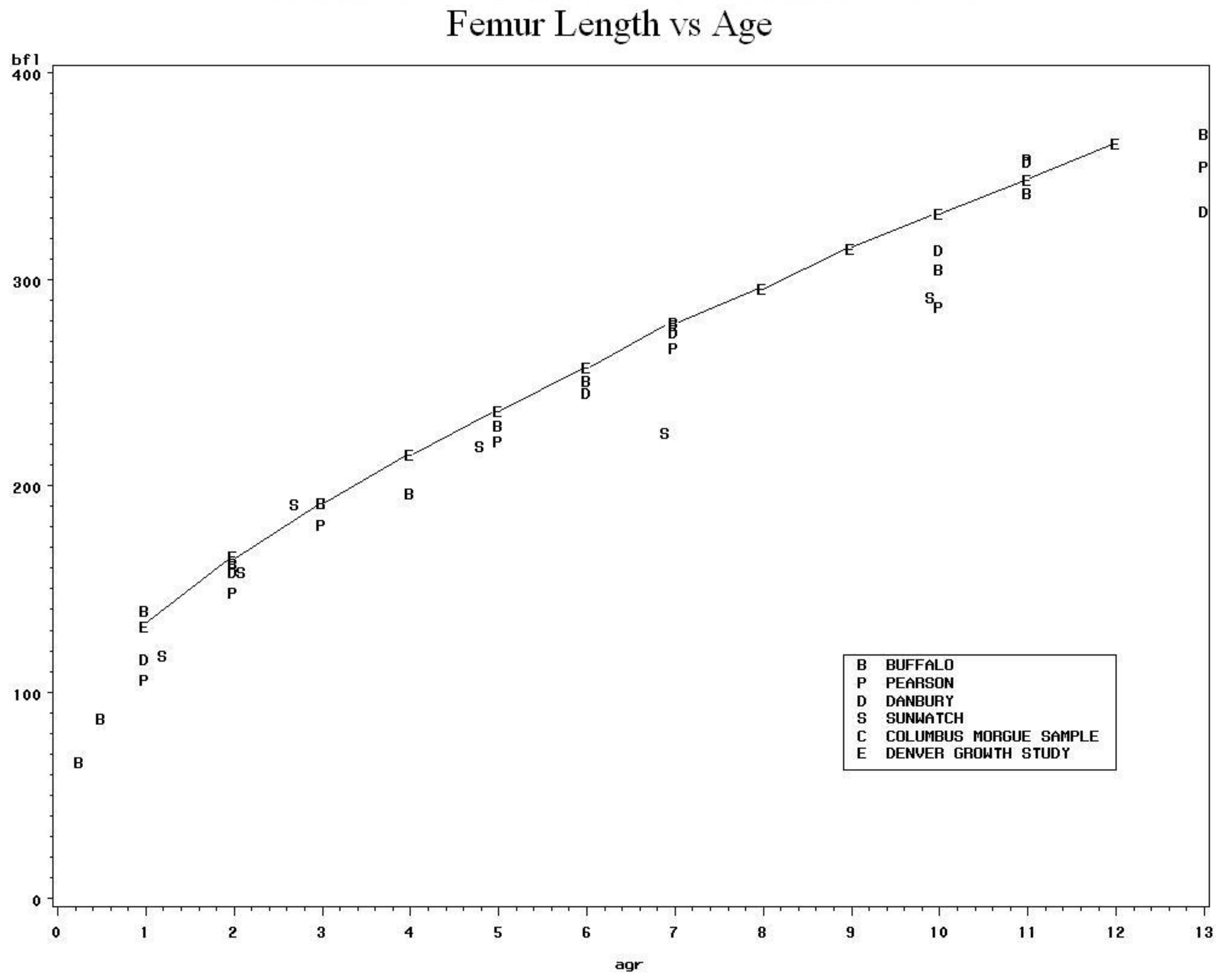

Figure 7 – Femur lengths of separate Native American samples and modern samples

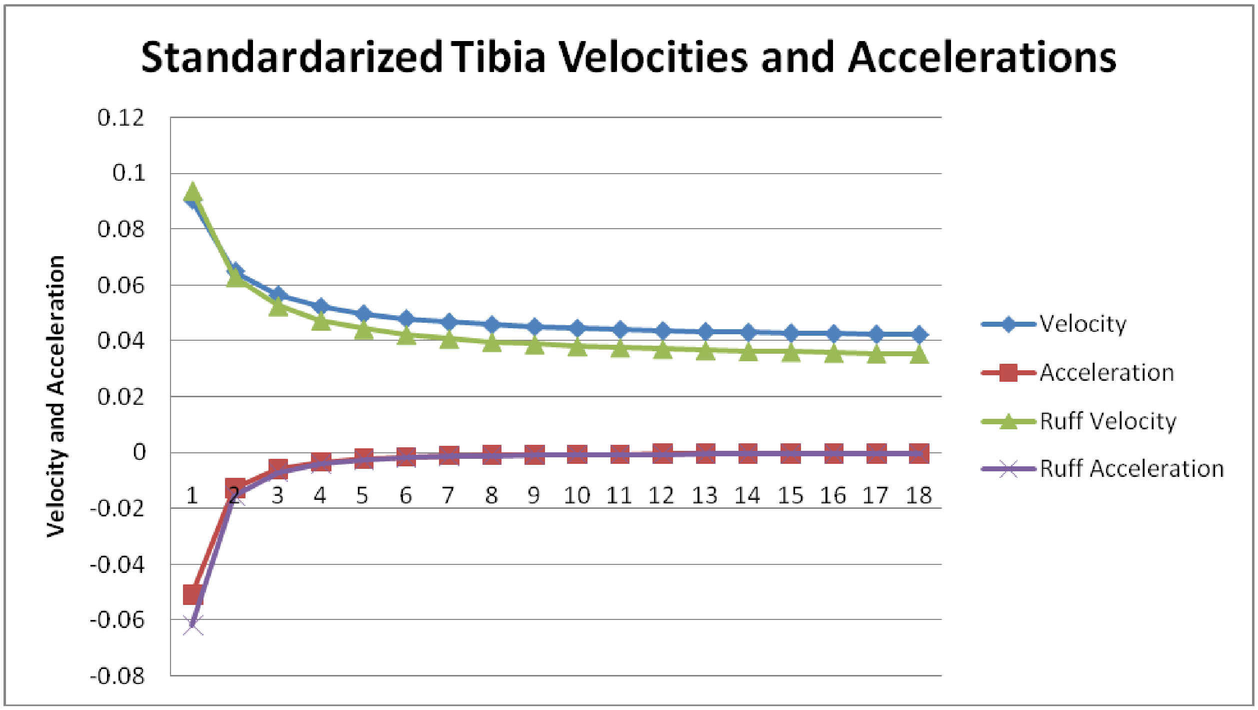

Figure 8 – Native American growth compared to Ruff's modern growth

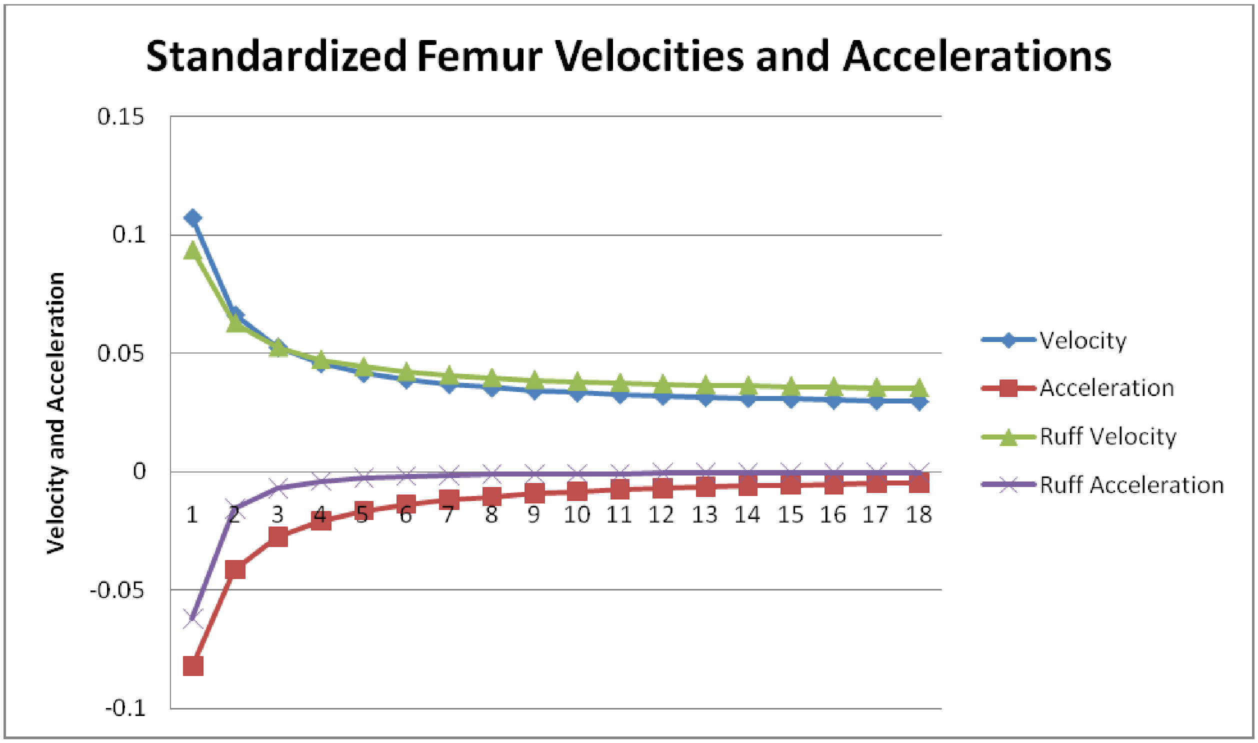

Figure 9 – Native American growth compared to Ruff's modern growth

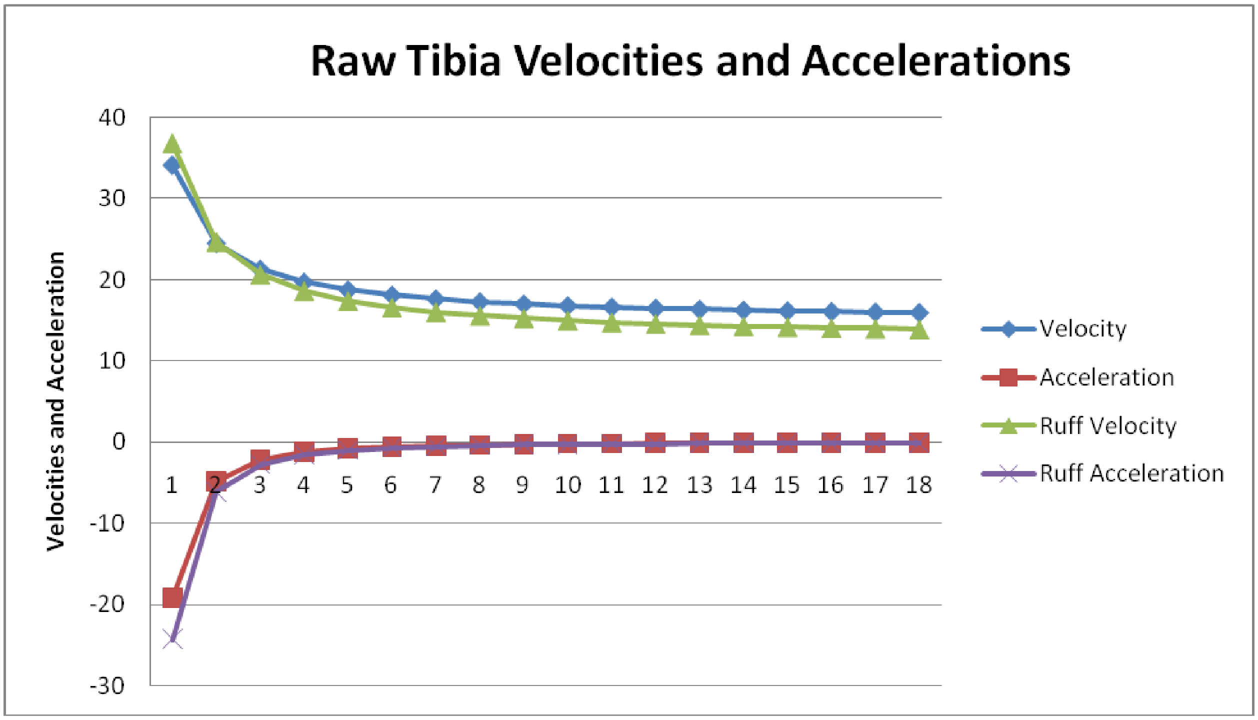

Figure 10 – Native American growth compared to Ruff's modern growth

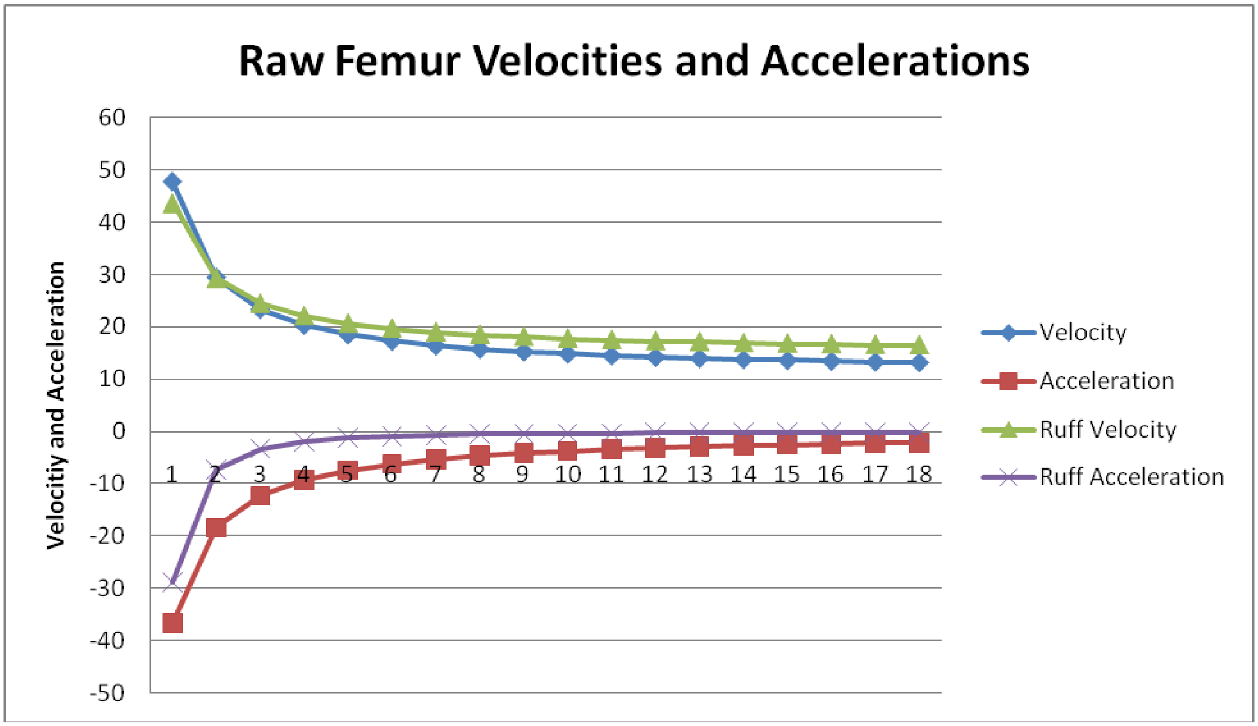

Figure 11 – Native American growth compared to Ruff's modern growth

Table 1 – Adult Stature

Method	Equation	Sex
Sciulli-Green	Y=2.443X+42.805	M
Y=Stature, X=Total Femur Length	Y=2.336X+44.253	F
Sciulli-Hetland	Y=39.92+2.56X	M
Y=Stature, X=Bicondylar Length	Y=47.23+2.33X	F
-	Y=41.55+2.5X	M
Y=Stature, X=XF	Y=47.31+2.27X	F
-	Y=56.11+2.62X	M
Y=Stature, X=CM	Y=55.57+2.58X	F
-	Y=53.28+2.67X	M
Y=Stature, X=XT	Y=56.37+2.51X	F
-	$Y=40.24+1.39\ (X_1+X_2)$	M
Y=Stature, X_1=BF, X_2=CT	$Y=45.35+1.34\ (X_1+X_2)$	F
-	$Y=40.2+1.39\ (X_1+X_2)$	M
Y=Stature, X_1=XF, X_2=XT	$Y=41.89+1.32\ (X_1+X_2)$	F
-	$Y=37.02+1.32\ (X_1+X_2+X_3)$	M
Y=Stature, X_1=BF, X_2=CT, X_3=FT	$Y=39.68+1.27\ (X_1+X_2+X_3)$	F
-	$Y=37.3+1.3\ (X_1+X_2+X_3)$	M
Y=Stature, X_1=XF, X_2=XT, X_3=FT	$Y=39.42+1.26\ (X_1+X_2+X_3)$	F

Table 2 – Adult Body Mass

Method	Equation	Sex
Grine Y=Stature, X=Femoral Head Dia.	Y=2.268X-36.5	Both
McHenry Y=Stature, X=Femoral Head Dia.	Y=2.239X-39.9	Both
Ruff et al.	Y=(2.741X-54.9) .9	M
-	Y=(2.426X-35.1) .9	F
Y=Stature, X= Femoral Head Dia.	Y=(2.16X-24.8) .9	Both

Table 3 – Juvenile Body Mass		
Age	Method 1 Y= Stature, X=Distal Femoral Met	Method 2 Y= Stature, X=Femur Head Dia.
1	Y=.188X+2.6	n/a
2	Y=.268X+.2	n/a
3	Y=.257X+1.5	n/a
4	Y=.328X-.7	n/a
5	Y=.367X-1.6	n/a
6	Y=.367X-.4	n/a
7	Y=.419X-1.6	Y=.495X+8
8	Y=.414X+.5	Y=.606X+6.1
9	Y=.694X-12.8	Y=1.55X-8.7
10	Y=.992X-29.5	Y=1.279X-12.2
11	Y=.938X-23.9	Y=1.626X-23
12	Y=1.351X-49.6	Y=1.85X-31.3
13	n/a	Y=1.83X-29.4
14	n/a	Y=1.438X-10.3
15	n/a	n/a
16	n/a	n/a
17	n/a	Y=1.75X-17.2

Table 4 – Juvenile Stature			
Age	Method 1 Y=Stature, X=FX	Method 2 Y=Stature, X=TX	Method 3 Y=stature,X_1=FX,X_2=TX
1	Y=.303X+32.6	Y=.353X+35.4	Y=.175 (X_1+X_2) +31.1
2	Y=.294X+35.7	Y=.38X+33.5	Y=.185(X_1+X_2)+29
3	Y=.31X+34.1	Y=.342X+39.9	Y=.174(X_1+X_2)+33
4	Y=.295X+37.7	Y=.327X+43.7	Y=.163(X_1+X_2)+37.7
5	Y=.311X+34.1	Y=.322X+45.3	Y=.168(X_1+X_2)+35.5
6	Y=.287X+40.5	Y=.33X+44.9	Y=.16(X_1+X_2)+39.5
7	Y=.294+39.1	Y=.325X+46.8	Y=.162(X_1+X_2)+38.6
8	Y=.294X+42.8	Y=.304X+52.9	Y=.153(X_1+X_2)+44.3
9	Y=.308X+ 35.6	Y=.324X+48.9	Y=.165(X_1+X_2)+38
10	Y=.292X+40.6	Y=.321X+50.1	Y=.160(X_1+X_2)+40.8
11a	Y=.306X+36.3	Y=.331X+47.7	Y=.165(X_1+X_2)+38.2
11b	Y=.279X+36.4	Y=.296X+47.3	Y=.155(X_1+X_2)+33.6
12a	Y=.32X+31.4	Y=.333X+47.9	Y=.148(X_1+X_2)+38.7
12b	Y=.29X+31.8	Y=.309X+43.3	Y=.158(X_1+X_2)+31.3
13	Y=.288X+33	Y=.321X+40.1	Y=.159(X_1+X_2)+32.1
14	Y=.294X+31.5	Y=.307X+46.8	Y=.145(X_1+X_2)+44.8
15	Y=.269X+43.8	Y=.273X+61.6	Y=.143(X_1+X_2)+47
16	Y=.27X+43.9	Y=.274X+62.7	Y=.149(X_1+X_2)+43.4
17	Y=.286X+37.4	Y=.281X+61.5	Y=.148(X_1+X_2)+38.7

Table 5 – Equations for Growth and their percentiles

Parameter	Estimate	F Value	25th Percentile	75th Percentile
Femur /Stage	43.7217	3307.03	38.62	48.82
	29.5705		27.92	31.21
	-37.7529		-46.04	-29.45
Femur/Age	120.8	1161.73	113.4	128.3
	11.1995		9.13	13.26
	36.5384		30.76	42.31
Distal Met/Stage	15.2403	658.23	13.69	16.79
	3.0957		2.55	3.63
	1.066		-1.57	3.7
Distal Met/Age	30.2876	135.2	27.33	33.24
	.3591		-.46	1.18
	8.159		5.92	10.39
Standard Femur/Age	.2721	1161.73	.25	.28
	.0252		.0206	.0299
	.0823		.06	.09
Standard Femur/Stage	.0985	3307.03	.08	.11
	.0666		.06	.07
	-.085		-.1	-.06
Standard Tibia/Age	.2307	593.46	.19	.26
	.0396		.03	.04
	.0509		.02	.07
Standard Tibia/Stage	.1022	2392.64	.08	.11
	.0715		.06	.07
	-.1101		-.13	-.08
Stature/Stage	47.5453	798.36	44.84	50.24
	7.194		6.04	8.34
	-3.2115		-8.39	1.97
Stature/Age	72.5135	872.56	69.79	75.22
	2.9033		2.15	3.65
	12.6484		10.58	14.71
Mass/Stage	1.2631	63.27	-1.53	4.06
	5.0239		3.68	6.35
	-13.1548		-18.7	-7.6
Mass/Age	2.7848	212.29	1.04	4.52
	3.3025		2.79	3.81
	-1.8841		-3.19	-.56
Tibia/Age	86.9725	593.46	74.75	99.19
	14.9195		11.34	18.49
	19.1921		11.02	27.35
Tibia/Stage	38.5277	2392.64	33.58	43.46
	26.9746		25.26	28.67
	-41.5176		-49.95	-33.08
Stature/Mass	249	168.46	177.2	320.8
	1.2221		.96	1.48
	-77.4121		-98.72	-56.1

Table 6 – Specific velocities of Native American sample compared to modern sample

Native American				Denver Growth Study		
Age	Fmet	Femur Length	Tibia Length	Fmet	Femur Length	Tibia Length
1	7.94	46.5	34.18	8.94	43.67	36.84
3	3.48	23.97	20.42	3.59	24.51	20.62
5	2.59	19.47	17.67	2.52	20.68	17.38
7	2.20	17.54	16.49	2.06	19.03	15.98
9	1.99	16.46	15.83	1.8	18.12	15.21
11	1.86	15.78	15.42	1.64	17.54	14.72

Table 7 – Adult Native American measurement means

Element	**Mean**
Femur Length	443.95 mm
Tibia Length	377.07 mm
Femur Head Diameter	44.39 mm
Age	34.94 years
Body Mass	62.74 kg
Stature	152.84 cm