Author: Tim Baron
4/16/2018

An Examination of the Relationship Between Various Human Bone Lengths and Gender

Abstract:

On March 8, 2018, CNN news reported that Richard Jantz, professor emeritus of anthropology at the University of Tennessee, attempted to use bone length data collected in 1940 to determine if bones found on the Pacific Island of Nikumaroro could be those of Amelia Earhart.

In 1940, Dr. D. W. Hoodless studied and measured these bones first hand and concluded that they belonged to a human male. The bones were lost shortly afterwards.

Richard Jantz used Dr. Hoodless's bone measurements from 1940 to perform a modern forensic analysis using information and technology not available at that time. In his opinion, what he found "strongly supports the conclusion that the Nikumaroro bones belonged to Amelia Earhart". However, other reporting indicates that this conclusion is suspect due to other circumstantial evidence surrounding the case.

Nonetheless, the idea of determining gender from bone measurements is an interesting one. This research project will look at raw data from various human bones and attempt to create models to accurately determine gender from bone length. This project will examine the mean and standard deviation between the various bones of each gender. It will analyze the correlations between height, humerus length, and femur length. Several logistic regressions will be run to model the relationship between bones and gender.

The results indicate that it is possible to predict gender using bone length. Predictions can be made using individual logistic regressions or multi-variable logistic regressions. Predictions when bone length height proportion data is used, but the predictions are less accurate.

Introduction:

Male and female bone length and height raw data was obtained from the Forensic Anthropology Data Bank for the following human bones: humerus, radius, ulna, femur, tibia, and fibula. Using this data, we will look for relationships between different bones lengths and gender. The goal is to see if we can find a reliable model or reliable models to determine gender from bone length.

The main goals of this project are to determine:

- Which single bone is the best predictor of gender?
- How can we best tell the difference between male and female bones?
- Does looking at multiple bones give more predictive power than looking at just one bone?
- Are men and women different in bone proportions after accounting for height?

Methods, Models, and Calculations:

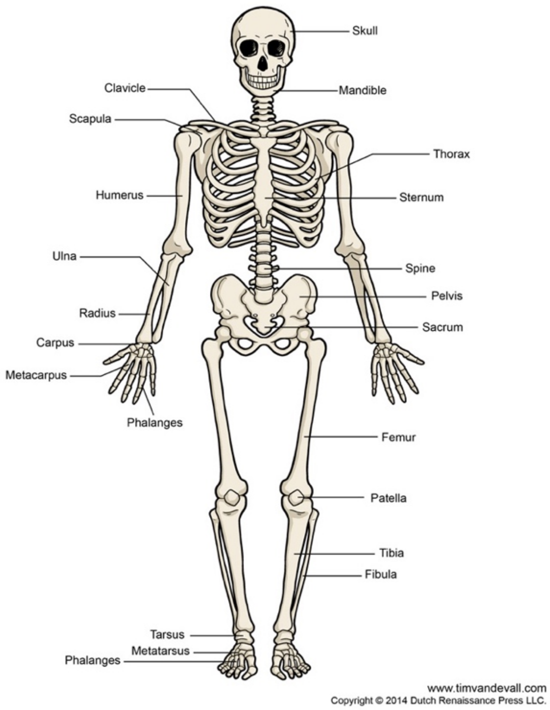
All calculations and graphing will be done in Excel except for the summary output data for logistic regressions which will be done using XLMiner in Google Sheets.

We will look at the correlation(s) between the largest bones (humerus and femur) and height.

A logistic regression will be done for each bone. A multi-variable logistic regression will be done for all bones. A multi-variable logistic regression using bone/height proportions will be done for all bones. A bone/height proportion logistic regression will be done for the humerus to see how it compares to the raw data (non-proportion) humerus logistic regression.

An example graph, calculated probabilities, and summary data will be shown for the humerus logistic regression. Only summary data will be shown for the remaining regressions (the graphs and summaries for all regressions can be found in the attached Excel workbook).

Skeletal Diagram for Reference:



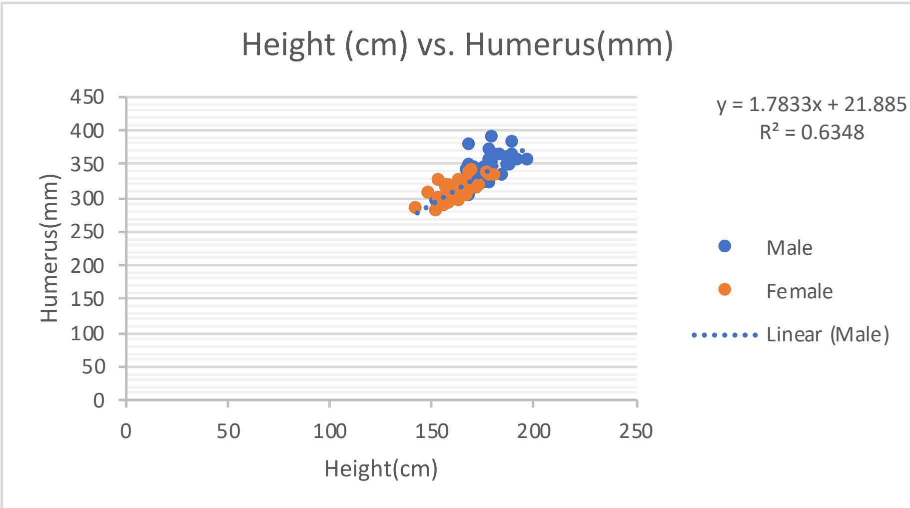
Mean Heights and Mean Bone Lengths:

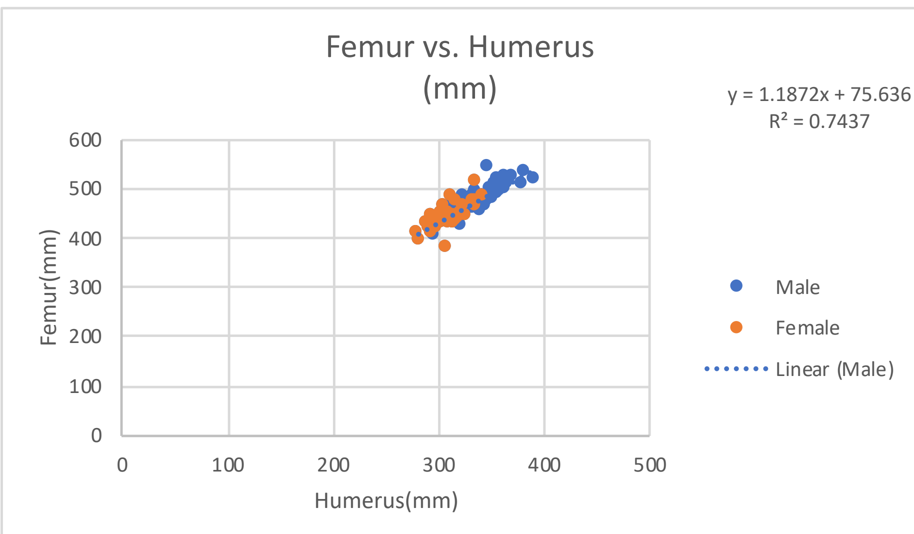
We will first compare the mean and overall height standard deviation for all of the bones for both males and females.

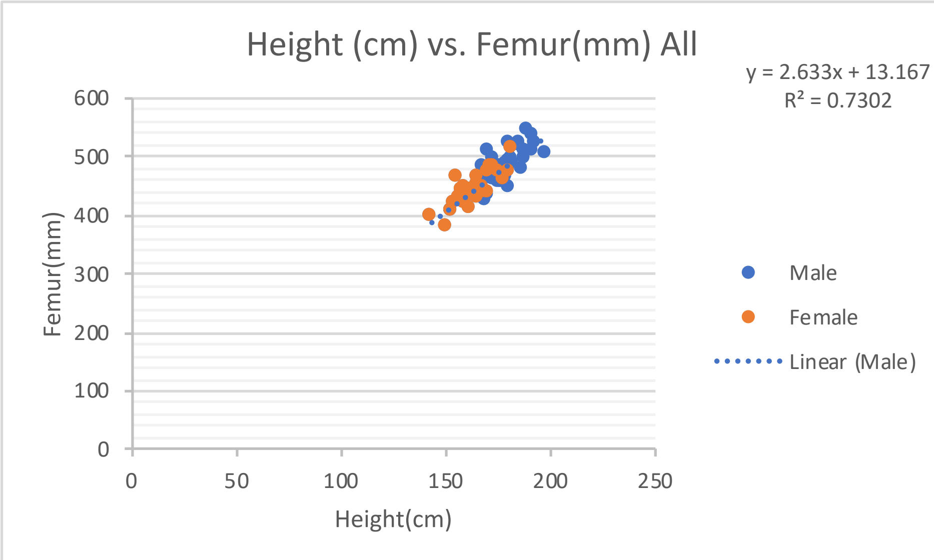
	Mean Height (cm)	Mean Humerus (mm)	Mean Radius (mm)	Mean Ulna (mm)	Mean Femur (mm)	Mean Tibia (mm)	Mean Fibula (mm)
All	171.4597701	327.6436782	248.908046	266.4252874	464.6206897	386.2068966	378.1609195
Male	177.893617	342.5744681	261.0638298	278.6170213	481.8510638	401.6170213	394.5319149
Female	163.9	310.1	234.625	252.1	444.375	368.1	358.925

Overall Height SD =	10.59157695

Correlation of Height, Humerus, and Femur:

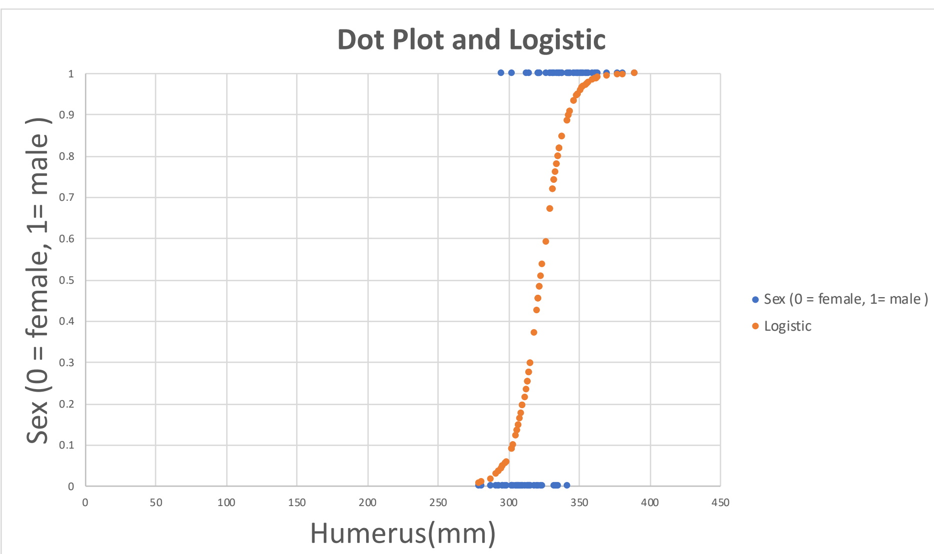






In the above graphs, looking at R^2, we see moderate correlations between height, femur length, and humerus length. We also see that male bones tend to be longer than female bones.

Graphed Logistic Regression, Probabilities, and Summary Data for the Humerus Bone:



SUMMARY OUTPUT							
Regression Statistics							
Chi Square	54.9093259						
Residual Dev	65.1344558						
# of iterations	7						
Observations	87						
	Coefficients	Standard Erro	P-value	Odd Ratio	Lower 95%	Upper 95%	Lower 95%	Upper 95%
Intercept	-36.280427	7.43355446	1.0575E-06	0	0	3.7245E-10	0	3.7245E-10
Humerus(mm)	0.11209469	0.02294437	1.0317E-06	1.11861878	1.06942867	1.17007147	1.06942867	1.17007147

Humerus(mm)	Sex (0 = female, 1= male)	p(male)
307	0	0.133847939
336	0	0.799534891
294	0	0.034737271
324	0	0.509562247
314	0	0.252996679
303	0	0.089828162
311	0	0.194821954
312	0	0.213008957
322	0	0.453649526
298	0	0.053342279
280	0	0.007436337
294	0	0.034737271
311	0	0.194821954
316	0	0.297652022
292	0	0.027955802
315	0	0.274761209
303	0	0.089828162
308	0	0.147384807
315	0	0.274761209
316	0	0.297652022
333	0	0.740218762
321	0	0.426039033
299	0	0.059294496
304	0	0.099424075
309	0	0.162034626
319	0	0.372333315
325	0	0.537516442
335	0	0.780964396
334	0	0.761187425
307	0	0.133847939
297	0	0.047957109
282	0	0.00928779
297	0	0.047957109
342	0	0.88654827
303	0	0.089828162
308	0	0.147384807
288	0	0.018036525
314	0	0.252996679
306	0	0.121377394
310	0	0.177836888
337	1	0.816900062
296	1	0.043090852
339	1	0.848086845
343	1	0.897343734
352	1	0.959955863
354	1	0.967738721
327	1	0.592554997
357	1	0.976737572
344	1	0.907219463
339	1	0.848086845
343	1	0.897343734
353	1	0.964049503
303	1	0.089828162
364	1	0.98925
349	1	0.944831838
323	1	0.481548123
350	1	0.950391681
350	1	0.950391681
337	1	0.816900062
344	1	0.907219463
360	1	0.983269709
347	1	0.93191163
330	1	0.670582723
322	1	0.453649526
332	1	0.718090841
322	1	0.453649526
332	1	0.718090841
323	1	0.481548123
335	1	0.780964396
330	1	0.670582723
313	1	0.232403707
336	1	0.799534891
390	1	0.999411005
356	1	0.974049817
362	1	0.986584682
322	1	0.453649526
337	1	0.816900062
363	1	0.987990163
355	1	0.971060719
378	1	0.997742792
370	1	0.994484211
333	1	0.740218762
342	1	0.88654827
347	1	0.93191163
315	1	0.274761209
363	1	0.987990163
382	1	0.998557229

Results:

Logistic Regression of the Humerus:

SUMMARY OUTPUT								
Regression Statistics								
Chi Square	54.9093259							
Residual Dev	65.1344558							
# of iterations	7							
Observations	87							
	Coefficients	Standard Erro	P-value	Odd Ratio	Lower 95%	Upper 95%	Lower 95%	Upper 95%
Intercept	-36.280427	7.43355446	1.0575E-06	0	0	3.7245E-10	0	3.7245E-10
Humerus(mm)	0.11209469	0.02294437	1.0317E-06	1.11861878	1.06942867	1.17007147	1.06942867	1.17007147

Logistic Regression of the Radius:

SUMMARY OUTPUT								
Regression Statistics								
Chi Square	50.7268588							
Residual Dev	69.3169229							
# of iterations	7							
Observations	87							
	Coefficients	Standard Erro	P-value	Odd Ratio	Lower 95%	Upper 95%	Lower 95%	Upper 95%
Intercept	-31.459148	6.75864862	3.2453E-06	0	0	1.2315E-08	0	1.2315E-08
Radius(mm)	0.12771503	0.02730629	2.9092E-06	1.13622916	1.07701753	1.19869609	1.07701753	1.19869609

Logistic Regression of the Ulna:

SUMMARY OUTPUT								
Regression Statistics								
Chi Square	49.9695634							
Residual Dev	70.0742183							
# of iterations	7							
Observations	87							
	Coefficients	Standard Erro	P-value	Odd Ratio	Lower 95%	Upper 95%	Lower 95%	Upper 95%
Intercept	-33.116775	7.09744122	3.071E-06	0	0	4.5595E-09	0	4.5595E-09
Ulna(mm)	0.12536589	0.02671902	2.7054E-06	1.13356314	1.07572792	1.1945078	1.07572792	1.1945078

Logistic Regression of the Femur:

SUMMARY OUTPUT								
Regression Statistics								
Chi Square	35.4975109							
Residual Dev	84.5462709							
# of iterations	6							
Observations	87							
	Coefficients	Standard Erro	P-value	Odd Ratio	Lower 95%	Upper 95%	Lower 95%	Upper 95%
Intercept	-25.55221	5.7477576	8.7648E-06	0	0	6.2419E-07	0	6.2419E-07
Femur(mm)	0.05566759	0.01248876	8.2954E-06	1.05724619	1.03168158	1.08344428	1.03168158	1.08344428

Logistic Regression of the Tibia:

SUMMARY OUTPUT								
Regression Statistics								
Chi Square	34.6614318							
Residual Dev	85.3823499							
# of iterations	6							
Observations	87							
	Coefficients	Standard Erro	P-value	Odd Ratio	Lower 95%	Upper 95%	Lower 95%	Upper 95%
Intercept	-22.450035	4.92077149	5.0596E-06	1.7786E-10	0	2.7456E-06	0	2.7456E-06
Tibia(mm)	0.05898955	0.01289298	4.7549E-06	1.06076415	1.03429473	1.08791098	1.03429473	1.08791098

Logistic Regression of the Fibula:

SUMMARY OUTPUT								
Regression Statistics								
Chi Square	41.638722							
Residual Dev	78.4050597							
# of iterations	7							
Observations	87							
	Coefficients	Standard Erro	P-value	Odd Ratio	Lower 95%	Upper 95%	Lower 95%	Upper 95%
Intercept	-26.674342	5.73846731	3.3462E-06	0	0	1.9956E-07	0	1.9956E-07
Fibula(mm)	0.07158228	0.01537876	3.2458E-06	1.07420653	1.0423111	1.10707799	1.0423111	1.10707799

Multi-Variable Logistic Regression for All Bones:

SUMMARY OUTPUT								
Regression Statistics								
Chi Square	67.63359016							
Residual Dev.	52.41019159							
# of iterations	8							
Observations	87							
	Coefficients	Standard Error	P-value	Odd Ratio	Lower 95%	Upper 95%	Lower 95%	Upper 95%
Intercept	-42.38023156	9.660934053	1.1505E-05	0	0	0	0	0
Humerus(mm)	0.120495223	0.042881791	0.004955087	1.128055352	1.037120845	1.226962974	1.037120845	1.226962974
Radius(mm)	0.085688567	0.099593831	0.389579462	1.089466979	0.896271628	1.324306451	0.896271628	1.324306451
Ulna(mm)	-0.010600732	0.090253418	0.906499356	0.989455258	0.829033943	1.180918725	0.829033943	1.180918725
Femur(mm)	-0.017817175	0.0319594	0.577189929	0.982340612	0.922695088	1.045841786	0.922695088	1.045841786
Tibia(mm)	-0.182895138	0.075776506	0.015795242	0.832855486	0.717907634	0.966208224	0.717907634	0.966208224
Fibula(mm)	0.168861048	0.070861894	0.017174067	1.183955615	1.03042804	1.360357874	1.03042804	1.360357874

Multi-Variable Logistic Regression for All Bones Using Bone/Height Proportions:

SUMMARY OUTPUT								
Regression Statistics								
Chi Square	21.50746495							
Residual Dev.	98.5363168							
# of iterations	6							
Observations	87							
	Coefficients	Standard Error	P-value	Odd Ratio	Lower 95%	Upper 95%	Lower 95%	Upper 95%
Intercept	-4.938391117	7.604654536	0.516085943	0.007166119	2.41096E-09	21299.90492	2.41096E-09	21299.90492
Humerus(mm)/Height (cm)	8.300305351	4.323469695	0.054880004	4025.101275	0.84068391	19271738.26	0.84068391	19271738.26
Radius(mm)/Height(cm)	31.76723268	12.08556592	0.008575562	6.25653E+13	3229.099986	1.21E+24	3229.099986	1.21E+24
Ulna(mm)/Height(cm)	-21.76511043	10.36263043	0.035698407	3.52803E-10	0	0.233463856	0	0.233463856
Femur(mm)/Height(cm)	-8.886851287	4.07249874	0.029097592	0.000138194	4.72033E-08	0.404582168	4.72033E-08	0.404582168
Tibia(mm)/Height(cm)	-17.90622374	7.56217583	0.017890984	1.67273E-08	0	0.04574689	0	0.04574689
Fibula(mm)/Height(cm)	18.77669617	7.613634962	0.013655759	142762956.9	47.19301302	4.3187E+14	47.19301302	4.3187E+14

Logistic Regression of the Humerus Using Bone/Height Proportions:

SUMMARY OUTPUT								
Regression Statistics								
Chi Square	3.55304511							
Residual Dev	116.490737							
# of iterations	5							
Observations	87							
	Coefficients	Standard Errc	P-value	Odd Ratio	Lower 95%	Upper 95%	Lower 95%	Upper 95%
Intercept	-9.6251054	5.41798833	0.07564905	6.605E-05	1.6146E-09	2.70190381	1.6146E-09	2.70190381
Humerus(mm)	5.12604242	2.83963388	0.07104695	168.349541	0.64433422	43985.8184	0.64433422	43985.8184

Conclusions:

Which single bone is the best predictor of gender?

When looking at the summary data for single bone logistic regressions we can see that the humerus has the highest Chi-Squared result of 54.9093259. Therefore, the most useful bones for gender prediction when looking at logistic regressions for each individual bone are (from best to worst predictor):

Bone	Chi-Squared
Humerus	54.9093259
Radius	50.7268588
Ulna	49.9695634
Fibula	41.638722
Femur	35.4975109
Tibia	34.6614318

How can we best tell the difference between male and female bones?

The multi-variable linear regression for all bones summary data we can see that only the humerus, tibia, and fibula are statistically significant. This can be determined by looking at the p-values for the bones against alpha = 0.05. The femur, radius, and ulna are not statistically significant. Therefore, the best way to tell the difference between a set of male and female bones would be to examine the humerus, tibia, and fibula together.

Bone	P-value
Humerus(mm)	0.00495509
Radius(mm)	0.38957946
Ulna(mm)	0.90649936
Femur(mm)	0.57718993
Tibia(mm)	0.01579524
Fibula(mm)	0.01717407

Does looking at multiple bones give more predictive power than looking at just one bone?

Comparing the chi-squared values for the individual logistic regression equations with the multi-variable linear regression, we can see that the individual equations summarize to:

Bone	Chi-Squared
Humerus	54.9093259
Radius	50.7268588
Ulna	49.9695634
Fibula	41.638722
Femur	35.4975109
Tibia	34.6614318

And the multi-variable linear regression summarizes to:

Chi Square	67.63359016

Thus, the multi-variable linear regression using multiple bones is a better predictor of gender.

Are men and women different in bone proportions after accounting for height?

Examining the results of the multi-variable linear regression for all bones using bone/height proportions we have a chi-squared result of:

Chi Square	21.50746495

If we compare this to the multi-variable linear regression using multiple bones (no proportions) chi-squared value of:

Chi Square	67.63359016

This indicates that we will get better results using the multi-variable linear regression and that it will be more difficult to predict gender with the bone/height proportion summary data.

Examining logistic regression of the humerus using bone/height proportions we have a chi-squared of:

Chi Square	3.55304511

If we compare this to the logistic regression of the humerus bone (no proportions) chi-squared value of:

Chi Square	54.9093259

This indicates that we will get better results using the non-proportion humerus bone logistic regression and that it will be more difficult to predict gender with the bone/height proportion humerus logistic regression summary data.

Men and women are still different in bone proportions after accounting for height. Predictions are more accurate when we do not use bone/height proportion data for the model.

Final Thoughts:

Cleary, there is some overlap in size between the bones of men and women. Looking at the mean and standard deviation for all bones and looking at the logistic regression summary data and probabilities, we do have some ability to predict gender from bone length, but there will be some bone lengths that will leave gender ambiguous such as:

Test Humerus for male (mm):	**323.66**
Pr(male) =	**50.00%**

References:

Data from Forensic Anthropology Data Bank (FDB)
http://www.utdanacenter.org/mathtoolkit/mmacd/curric/pr/pdf/pr-tg.pdf

https://edition.cnn.com/2018/03/08/health/amelia-earhart-bones-island-intl/index.html

https://www.timvandevall.com/templates/human-skeleton-diagram-printable/

Introduction to Statistics and Data Analysis, 4th Edition - by Rosy Peck (Author), Chris Olsen (Author), Jay L. Devore (Author)

What is a p-value anyway? 34 Stories to Help You Actually Understand Statistics 1st Edition - by Andrew J. Vickers (Author) (used for information on logistic regression)