The Craniometric Value of Foramen Magnum Length & Nasal Breadth:

A Statistical Exploration of the Significance of Variation Across Sex & Populations

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ANT407H5

Final Project

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December 7, 2019

INTRODUCTION

Craniometric analysis, or measurements of the skull, has long been employed in anthropology to study skeletal variation (Dudzik & Kolatorowicz, 2016). Craniometry grew to popularity during the nineteenth century, with the rise of theories of classification such as those of Carolus Linneaus, who aimed to use cranial variation to classify humans into racial groups (Dudzik & Kolatorowicz, 2016). However, as an attempt to scientifically justify the prominent belief in racial hierarchies at the time, these classifications were inaccurate reflections of human cranial variation (Dudzik & Kolatorowicz, 2016). It was not until the early twentieth century when physical anthropologists began using statistical analyses to establish statistically significant craniometric variations (Dudzik & Kolatorowicz, 2016). Throughout the twentieth century, quantitative datasets, data collection techniques, and statistical analyses flourished in the field (Dudzik & Kolatorowicz, 2016). W.W. Howells contributed to the growth of craniometry by collecting the largest international craniometric dataset, which have repeatedly been studied over time, and will be the subject of this study (Dudzik & Kolatorowicz, 2016; Howells, 1973; Howells Kittery Point, 1996).

Howells also contributed to craniometry by re-establishing populations to be based on geographic locations rather than outdated racial classifications (Dudzik & Kolatorowicz, 2016). Cranial measurements have repeatedly been established in the literature to reflect geographic locations and environment, including in Howell's work over the years (Howells, 1973, 1989, 1995; Howells Kittery Point, 1996; Nowaczewska, Dbrowski, & Kuÿmiñski, 2011). An interesting correlation has been noted in the literature as body size tends to vary according to latitude (Teplitsky & Millien, 2014). This correlation is based on Bergmann's and Allen's Rules, which take note of a correlation between warm climates and small body size as well as cold climates and large body sizes, respectively (Teplitsky & Millien, 2014). Bergmann explains this rule as a result of surface area to volume ratios; in cooler climates, species adapt to have larger bodies and consequently lower surface area to volume ratios so that they radiate less body heat, while smaller animals reside in warmer climates, with their higher surface area to volume ratios facilitating the radiation of heat to help them keep cool (Teplitsky & Millien, 2014). According to the literature, various cranial features, including nasal traits such as nasal breadth, vary based on geography and corresponding climates to reflect Bergmann and Allen's rules (Franciscus & Long, 1991; Zaidi et al., 2017). Nasal breadth has also been shown to be sexually dimorphic, with robust males possessing larger nasal breadths in comparison to their more gracile female counterparts (Holton, Yokley, Froehle, & Southard, 2014). Although some cranial measurements, such as nasal breadth, have been established as a sex and population variant, there are still gaps in the literature regarding other traits (Holton et al., 2014). For instance, size of the foramen magnum has been established to be sexually dimorphic within populations; however, there is a gap in the literature on how foramen magnum length varies across populations (Gruber, Henneberg, Böni, & Rühli, 2009; Moodley, Rennie, Lazarus, & Satyapal, 2019; Seifert, Friedl, Chaumoitre, & Brůžek, 2017; Zdilla, Russell, Bliss, Mangus, & Koons, 2017).

The objective of this paper is to study foramen magnum length in the context of population latitude and sexual dimorphism to explore if it is a craniometric trait that can be used to assess sex and population in skeletal remains. Nasal breadth, which has been established in the literature to demonstrate both sexual dimorphism and population variation, will also be explored for comparative purposes (Franciscus & Long, 1991; Holton et al., 2014; Zaidi et al., 2017). This study involves research questions which inquire about whether both foramen magnum length and nasal breadth vary according to population and sex, whether there is a correlation between foramen magnum length and nasal breadth across populations, and, finally, whether there is a correlation between foramen magnum length and population latitude. These research questions are based on the following assumptions: 1) Skulls are subjected to regional genetic adaptations which persist in a population over time. This assumption originates from Howells' craniometric measurements, in the hope that measurements from past populations reflect present-day variation (Howells, 1973). 2) Following Howells, population groups are defined by geography, which is reflected in latitude (Howells, 1973). 3) Craniometric measurements of the sample skulls are representative of their source population. 4) Nasal breadth is a population variant that varies according to latitude and can therefore be used as a standard against which variation in foramen magnum length can be compared (Franciscus & Long, 1991; Holton et al., 2014; Zaidi et al., 2017).

MATERIALS & METHODS

Description of Dataset & Collection Methods

The data analyzed in this paper originates from W. W. Howells' *Cranial Variation in Man: A Study by Multivariate Analysis of Patterns of Difference Among Recent Human Populations* (Howells, 1973). Howells conducted a multivariate analysis by collecting cranial measurements between 1965 and 1980 to establish variation that reflects population affinities in skull shape (Howells, 1973). Howell's craniometric dataset includes up to 82 cranial measurements examined on a sample size of 2524 crania across 28 different populations (Howells, 1973; Howells Kittery Point, 1996). The dataset focuses on continuous numerical data (cranial measurements) rather than categorical data (morphological traits) (Howells, 1973). Specimens with full crania (without the mandible, due to poor preservation) were chosen by Howells from available collections of various populations to maximize the number of cranial landmarks measured (Howells, 1973). However, due to the rarity of perfectly preserved skulls, the sample set is limited in its representation of actual populations (Howells, 1973). Furthermore, some cranial measurements were estimated as not all sampled skulls were sufficiently preserved for all 82 cranial measurements (Howells, 1973).

Howells redefined populations to be based on geography rather than human constructs of race; his dataset samples most main geographic regions of human habitation (Appx. 1) (Howells, 1973). Fifty to fifty-five skulls of each sex were selected for each population (Howells, 1973). However, the sex of most skulls were unknown as is consistent in skeletal recovery (Howells, 1973). Therefore, Howells assessed the sex of each skull by examining sexually dimorphic traits, including supraorbital ridges, upper orbital margins, zygomatic arches, and base and nuchal areas (Howells, 1973). Intra-observer error was minimized as Howells repeatedly examined specimens following blinded models (Howells, 1973). Inter-observer error was also minimized by comparison with previous sex assessments conducted by other academics (Howells, 1973).

This study will only be examining two variables: 1) foramen magnum length (the measurement from the basion to the opisthion, measured using the sliding calipers), and 2) nasal breadth (the widest distance between the anterior and lateral edges of the nasal aperture, measured using the dial sliding calipers) (Howells, 1973). Populations of interest were chosen from Howells' dataset based on latitude, determined using Google Earth, to reflect geographic location of populations (Appx. 1) (Howells, 1973). However, since the Zulu and Bushman are associated with multiple geographic locations, they will not be included for the purposes of this study (Appx. 1). Furthermore, populations only ranged from latitudes of 43°53'16"S (Tasmania) to 62°35'33"N (Eskimo); unfortunately, only five populations in the southern hemisphere were sampled (Appx. 1). Additionally, both the Tasmanians and Yauyos originated from various collections with non-specific origins and so were not considered in this study; therefore, this study is unable to encompass the variation of the southern hemisphere. Ultimately, seven populations were chosen from the initial seventeen to represent various latitudes (Appx. 1). All statistical tests were performed using PAST Version 3 while all tables and graphs were created using both PAST Version 3 and Excel 2016.

Hypotheses

The first hypothesis examines whether foramen magnum length shows significant variation between sex or population. Significant variation in foramen magnum length may reflect differences in robusticity between males and females and between geographic populations (Zdilla, Russell, Bliss, Mangus, & Koons, 2017). The data was tested for normality using the Shapiro-Wilk test, QQ plot, and histogram to determine whether parametric or non-parametric tests should be performed (Madrigal, 2012). Given its normality and the analysis of ratio scale data of multiple samples across two grouping variables (sex and population), the Two-Way ANOVA test was selected. The Two-Way ANOVA examines the significance of variation in two different variables (sex and population) and their possible interaction (ie. combined effect) (Madrigal, 2012). Summary statistics and boxplots were created for both sex and population while the Graph of Means was plotted to depict trends in mean foramen magnum length (Madrigal, 2012). Following these plots, the Tukey’s Pairwise Post-Hoc Test assessed which pairs of groups were driving the significance in variation (Madrigal, 2012).

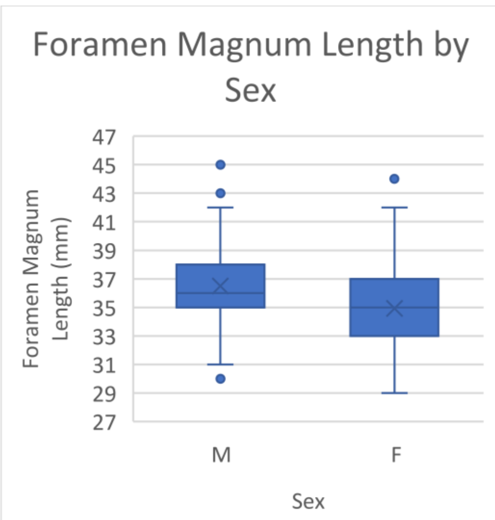
The second hypothesis assesses whether nasal breadth varies significantly between sex or population. Significant variation in nasal breadth may reflect differences in size due to sexual dimorphism and population adaptations to their environment, as seen in the literature (Franciscus & Long, 1991; Holton et al., 2014; Zaidi et al., 2017). Similar to the first hypothesis, normality was assessed using the Shapiro-Wilk test, QQ plot, and histogram (Madrigal, 2012). Since the data is normal, the parametric Two-Way ANOVA was conducted to assess the significance of variation in ratio data (nasal breadth) between multiple samples across two grouping variables (Madrigal, 2012). Summary statistics and boxplots were assembled for both sex and population while a Graph of Means and Tukey’s Pairwise Post-Hoc Test were performed to assess the trends and significant driving factors of the variation (Madrigal, 2012).

The third hypothesis examines the correlation between the mean foramen magnum lengths and nasal breadths. Significant correlation may indicate that foramen magnum length, like nasal breadth, may also be useful in assessing sex and ancestry in skeletal analysis (Franciscus & Long, 1991; Holton et al., 2014; Zaidi et al., 2017). Summary statistics, tables and boxplots were constructed to assess whether this correlational relationship based on mean measurements for populations as well as combined sex and population groups (Drennan & Contributions, 2009; Madrigal, 2012). The Shapiro-Wilk test was conducted to assess the data’s normality and, as a result, the parametric Pearson’s correlation coefficient was used to quantify the correlation between the two variables (Madrigal, 2012).

The fourth hypothesis explores whether there is correlation between foramen magnum length and latitude of population groups. Significant correlation may suggest that foramen magnum length follows Bergman's rule, varying by latitude or climate to produce larger foramen magnum lengths in cold temperatures, where populations are typically robust (Teplitsky & Millien, 2014). Summary statistics, tables and boxplots were constructed to depict relationships between foramen magnum length and population latitude (Drennan & Contributions, 2009; Madrigal, 2012). Similar to the previous correlation test, the Shapiro-Wilk test determined normality and the parametric Pearson's correlation coefficient was used to quantify the relationship between two variables (Madrigal, 2012). For all following statistical tests, an alpha level of 0.05 will be used to assess significance.

RESULTS

TEST 1: Significance of Variation in Foramen Magnum Length



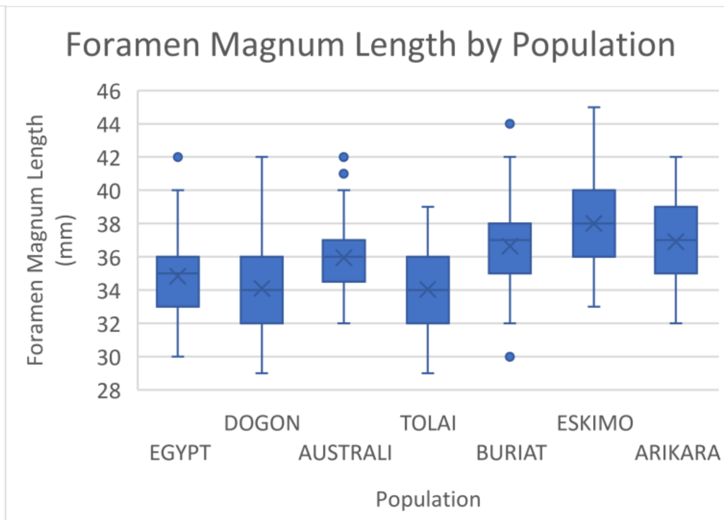


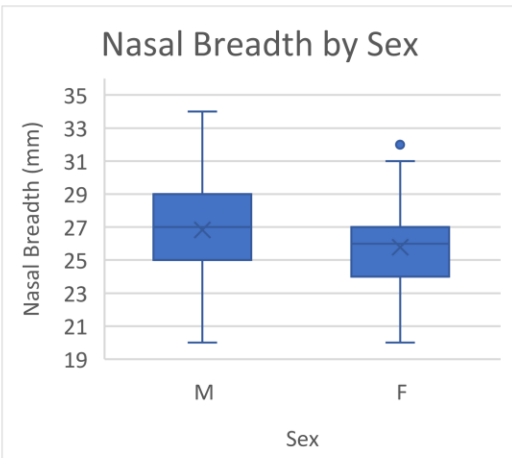
Figure 1. Boxplots Depicting Foramen Magnum Length Across Sex.

Figure 2. Boxplots Depicting Foramen Magnum Length Across Populations.

The Shapiro-Wilk test, $W(706) = 0.9853$, $p < 0.01$ suggests that the null hypothesis of normality should be rejected; however, it is extremely powerful and sensitive to large sample sizes (Mohd Razali & Bee Wah, 2011). Considering $n = 707$, the QQ plots and histograms were also examined, showing that the dataset follows a normal distribution; therefore, the null hypothesis of normality can be rejected (Appx. 2-5). The Two-Way ANOVA for sex, $F(1) = 86.97$, $p < 0.01$, and population $F(6) = 48.12$, $p < 0.01$, shows significant variation; however, their interaction does not show significant variation, $F(6) = 1.352$, $p = 0.2317$ (Appx. 6). This suggests that foramen magnum length varies due to sexual dimorphism and population individually, but not due to their combined effect; thus we cannot reject the null hypothesis that foramen magnum length does not vary according to sex and population combined. The sex-based boxplots (Fig. 1) emphasize sexual dimorphism; males ($M = 36.4876$, $SD = 2.523$) show a higher interquartile range of 35-38mm while females ($M = 34.933$, $SD = 2.716$) show a lower interquartile range of 33-37mm (Appx. 2). Similarly, the population-based boxplots highlight population variation (Fig. 2). The Buriat ($M = 36.643$, $SD = 2.367$), Eskimo ($M = 38$, $SD = 2.275$), and Arikara ($M = 36.913$, $SD = 2.466$) show greater means and ranges while the Egyptian ($M = 34.829$, $SD = 2.244$), Australian ($M = 35.951$, $SD = 2.085$), and Tolai ($M = 34.045$, $SD = 2.352$) show lower means and ranges, although there are outliers in the Egyptian, Australian, and

Buriat (Appx. 3). Interestingly, the Dogon (*M* = 34.091, *SD* = 2.635) has a lower average but has a relatively wide range that also includes much of the higher measurements (Appx. 3). Tukey's Post-Hoc indicates that the significance in foramen magnum length between sex is driven by the sexual dimorphism in all populations except for the Buriat and Eskimo, reinforced by the proximity of the means for these two populations in the Graph of Means (Appx. 7-8). Although there is significant variation between many populations, the interactions involving the Dogon and Eskimo appear to be driving the variation, reflecting their positions as the populations with the lowest and greatest average foramen magnum lengths in the Graph of Means respectively (Appx. 7-8). The sums of squares indicate that 8.1% of variation is attributable to sex, 26.9% to population, <1% to their interaction, and 64.6% to other factors (Appx. 6).

TEST 2: Significance of Variation in Nasal Breadth



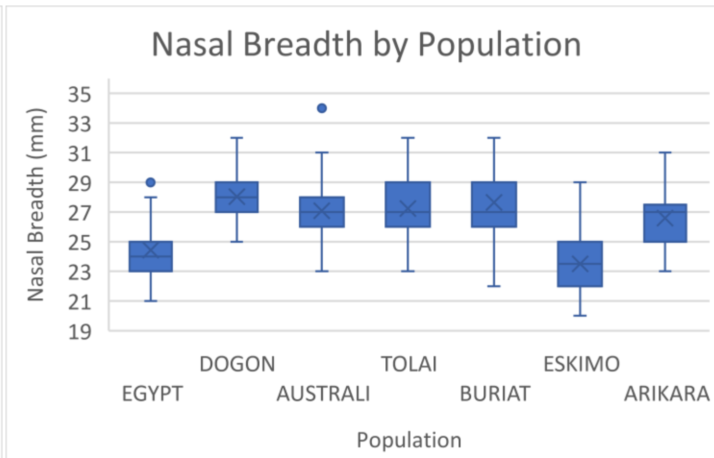


Figure 3. Boxplots Depicting Nasal Breadth Across Sex.

Figure 4. Boxplots Depicting Nasal Breadth Across Populations.

The Shapiro-Wilk test, $W(706) = 0.9819$, $p < 0.01$ suggests that the null hypothesis of normality should be rejected; however, the QQ plot and histogram suggest that the data is normally distributed, thus the null hypothesis of normality cannot be rejected (Appx. 9-12). (Mohd Razali & Bee Wah, 2011). Based on the Two-Way ANOVA, sex, $F(1) = 62.61$, $p < 0.01$, and population $F(6) = 105.4$, $p < 0.01$, show significant variation, but their interaction does not, $F(6) = 1.849$, $p = 0.087$ (Appx. 13). This suggests that although nasal breadth varies by sex and population individually, it does not vary based on their combined effect, so the null hypothesis of insignificant variation can be rejected. The boxplots (Fig. 3) depict sexual dimorphism as males (*M* = 26.821, *SD* = 2.530) show a higher interquartile range of 25-29 mm while females (*M* = 25.791, *SD* = 2.218) show a lower interquartile range of 24-27 mm (Appx. 9). Similarly, boxplots highlight population variation (Fig. 4). Interestingly, the Egyptians (*M* = 24.441, *SD* = 1.672), Eskimo (*M* = 23.5, *SD* = 1.626), and Arikara (*M* = 26.594, *SD* = 1.793) have mean nasal breadths under 26.6 mm while all other populations are between 27-28.1 mm; all populations show similar variation, with all standard deviations being between 1.6-2.2 (Appx. 10). Tukey's Post-Hoc indicates that sexual dimorphism of nasal breadth is driven by the Australians, Buriat, and Tolai, as shown in the Graph of Means where the averages for males and females in all other populations are close or even overlapping (Appx. 14-15). Furthermore, the interactions involving the Egyptians and Eskimo appear to be driving the variation, reflecting them being the lowest and most divergent in the Graph of Means (Appx. 14-15). The sums of squares indicate that 4.472% of variation is due to sex, 45.167% to population, <1% to their interaction, and 49.5% to other factors (Appx. 6).

TEST 3: Correlation of Foramen Magnum Length & Nasal Breadth

The population means for foramen magnum length and nasal breadth (Appx. 16) were assessed by the Shapiro-Wilk test. Both Foramen Magnum Length Means, $W(6) = 0.9295$, $p = 0.5469$; and Nasal Breadth Means, $W(6) = 0.8554$, $p = 0.1377$, showed normality. Foramen Magnum Length and Nasal Breadth across populations, assessed using Pearson's linear correlation coefficient, did not show significant correlation, $r(5) = -0.47456$, $p = 0.2819$. Pearson's correlation coefficient shows a moderate, but not significant, negative relationship, thus the null hypothesis of no significance cannot be rejected. As seen in Fig. 5, Foramen Magnum Length ($M = 35.782$, $SD = 1.514$) & Nasal Breadth ($M = 26.365$, $SD = 1.717$) across Populations show a slight negative trend; as foramen magnum length increases, nasal breadth tends to decrease (Appx. 17). However, this relationship is not strong; most populations, especially the Egyptian and Eskimo, deviate greatly from the line of best fit.

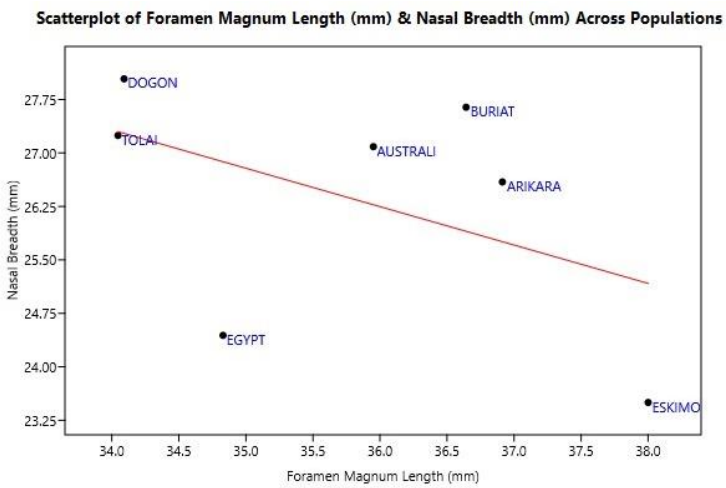


Figure 5. Scatterplot of Foramen Magnum Length & Nasal Breath Across Populations.

The combined sex and population means for foramen magnum length (Appx. 18) showed normality, $W(13) = 0.9271$, $p = 0.2775$; nasal breadth means also showed normality, $W(6) = 0.9026$, $p = 0.1229$. Foramen Magnum Length and Nasal Breadth across both sex and populations, assessed using Pearson's linear correlation coefficient, did not show significant correlation, $r(12) = -0.51071$, $p = 0.062016$. Pearson's correlation coefficient indicates a moderate, but not significant, negative relationship, thus the null hypothesis of no significance cannot be rejected. As seen in Fig. 6, Foramen Magnum Length ($M = 35.675$, $SD = 1.306$) & Nasal Breadth ($M = 26.278$, $SD = 1.507$) across Populations also show a slight negative trend, showing that as foramen magnum length increases, nasal breadth tends to decrease (Appx. 19).

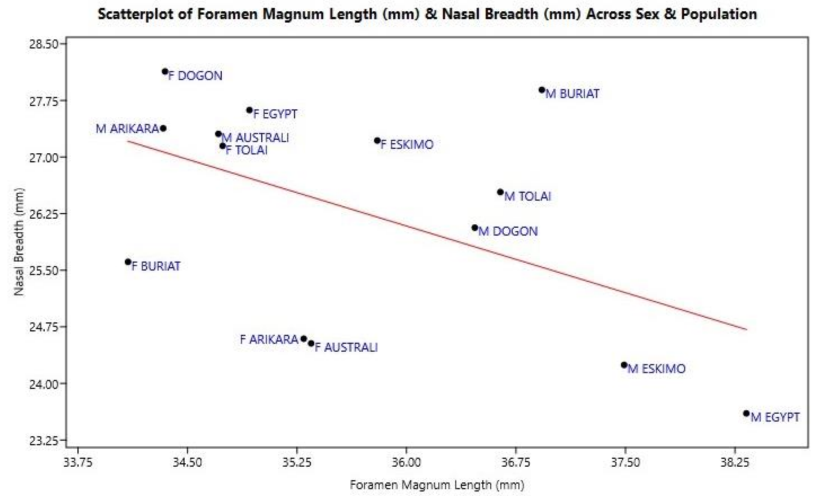
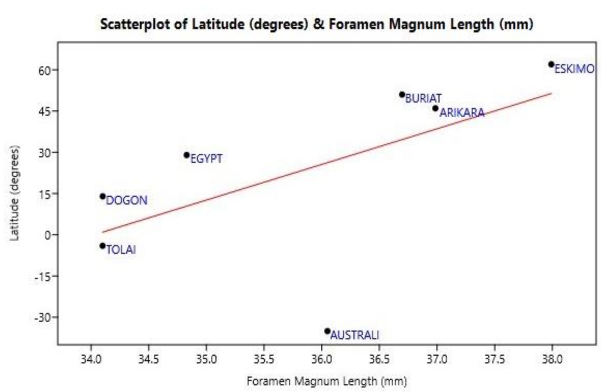


Figure 6. Scatterplot of Foramen Magnum Length & Nasal Breath Across Sex & Population.

TEST 4: Correlation of Foramen Magnum Length & Nasal Breadth with Latitude

Latitude was determined by the Shapiro-Wilk test to be normally distributed, $W(6) = 0.9459$, $p = 0.6923$, while Foramen Magnum Length Means, $W(6) = 0.9295$, $p = 0.5469$, have already been established as normal (Appx. 20). Foramen Magnum Length and Latitude across populations, assessed using Pearson's linear correlation coefficient, did not show significant correlation, $r(5) = 0.57335$, $p = 0.1784$. Pearson's correlation coefficient shows a moderate, but not significant, positive relationship, thus the null hypothesis of no significance cannot be rejected. As seen in Fig. 7, Foramen Magnum Length ($M = 35.822$, $SD = 1.516$) & Latitude ($M = 23.286$, $SD = 34.262$) across Populations show a slight positive trend; as latitude increases, foramen magnum length also tends to increase (Appx. 21). However, this relationship is not strong, especially since the Australian population is such an extreme outlier.



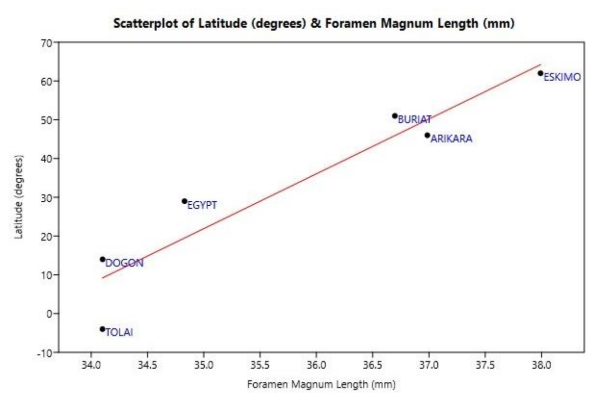


Figure 7. Scatterplot of Latitude & Foramen Magnum Length Across Population.

Figure 8. Scatterplot of Latitude & Foramen Magnum Length Across Population – With Australian Population Removed.

The Australian population appears to be an outlier; with it removed, the data is still normally distributed based on the Shapiro-Wilk test, $W(5) = 0.8803$, $p = 0.2703$ for Foramen Magnum Length and $W(5) = 0.9581$, $p = 0.805$ for Latitude. When not including the Australian population, Pearson's linear correlation coefficient shows a strong correlation, $r(4) = 0.94423$, $p = 0.0045785$, between latitude and foramen magnum length across population. This indicates that the Australian population may be skewing the data and there may be a strong positive correlation where as latitude increases, foramen magnum length also increases.

Latitude was previously determined to be normally distributed, while Nasal Breadth Means were assessed by the Shapiro-Wilk Test to also show normality, $W(5) = 0.8651$, $p = 0.1681$ (Appx. 22). Nasal Breadth and Latitude across populations, assessed using Pearson's linear correlation coefficient, did not show significant correlation, $r(5) = -0.48341$, $p = 0.27176$. Pearson's correlation coefficient shows a moderate, but not significant, negative relationship, thus the null hypothesis of no significance cannot be rejected. As seen in Fig. 9, Nasal Breadth ($M = 26.377$, $SD = 1.685$) & Latitude ($M = 23.286$, $SD = 34.262$) across Populations show a slight negative trend; as latitude increases, nasal breadth tends to decrease (Appx. 23). However, this relationship is not strong, since the Australian population strongly deviates from the overall trend once again.

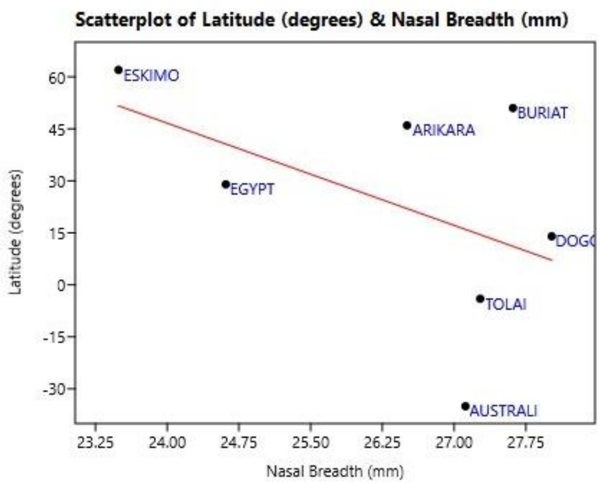


Figure 9. Scatterplot Depicting Latitude & Nasal Breadth Population

DISCUSSION

The results of the first test reject the null hypothesis of no significance and support the alternative hypothesis of significant variation, by showing that foramen magnum length varies significantly across sex and population individually (but not when considering both variables combined). This suggests that foramen magnum length may be a craniometric trait with significant variation, reflecting sexual dimorphism and ancestry. Based on the Two-Way ANOVA and boxplots, males tend to show larger foramen magnum length, expressing their skeletal robusticity (Gruber et al., 2009; Moodley et al., 2019; Seifert et al., 2017; Zdilla et al., 2017). Foramen magnum length also significantly varies according to population, with the three northernmost populations, the Buriat, Eskimo, and Arikara showing a greater average foramen magnum length. Furthermore, a greater proportion of variation is due to population rather than sex. These results suggest that foramen magnum length may vary according geographic environment or adaptations of populations, which will be further explored in the fourth test.

The results of the second test also reject the null hypothesis of insignificance and support the alternative hypothesis of significant variation, showing that nasal breadth varies according to sex and population, but not by their combined interaction. Males tend to show larger nasal breadths, which can be inferred to reflect their greater cranial robusticity over their more gracile female counterparts (Ashok, Subramani, & Marx, 2007). Interestingly, most populations appear to have similar average nasal breadth measurements as well as ranges, while three of the northernmost populations, the Egyptians, Eskimo, and Arikara express smaller average nasal breadths and show higher ranges. This can be inferred to be related to climate, as the literature establishes that narrow noses are common in colder climates (Zaidi et al., 2017). The Egyptian and Eskimo populations, which have the most distinct centre and spread of data based on their boxplots (Fig. 4), also tend to be driving variation between populations. Interestingly, nasal breadth is only 4.472% driven by sex while a much larger proportion of its variation is driven by population, at 45.167%. This suggests that although its variation between sexes are significant, its population variance may be inferred to be a more reliable driving factor. This can be interpreted to indicate that nasal breadth is a craniometric trait that is primarily influenced by climate and environment associated with latitude.

The third test was meant to be a comparative analysis between the two previously assessed variables. Since nasal breadth has been established to reflect population variation, foramen magnum length (variable of interest), was compared against it to support its statistical validity and examine if interesting trends are present (Zaidi et al., 2017). Surprisingly, the results show that foramen magnum length and nasal breadth are not significantly correlated, and the null hypothesis of no significance cannot be rejected. However, when examining their relationship across combined sex and population groups, a p-value of 0.062, which is extremely close to the alpha-value, suggests that a possible correlation or relationship between them is still worth exploring. Across both populations as well as combined sex and population, the data shows a moderate negative trend as groups with larger foramen magnum lengths tend to have smaller nasal breadths. This is an interesting trend as one might expect that there would be a positive correlation between these two factors as a result of relative cranial robusticity leading to both greater nasal breadths and foramen magnum lengths in certain populations (Ashok et al., 2007). However, the negative trend in the scatterplots (Fig. 4, Fig. 5) suggest that while foramen magnum length reflects Bergmann's rule of increased robusticity in colder climates, nasal breadth may be influenced by other factors, such as lower humidity in cold climates that do not require large nasal apertures for respiration (Franciscus & Long, 1991; Teplitsky & Millien, 2014; Zaidi et al., 2017).

The results of the fourth test show that, based on Pearson's correlation coefficient, foramen magnum length and population latitude are not significantly correlated and the null hypothesis of no significance cannot be rejected. However, there appears to be a moderate positive correlation between the two variables; populations residing at higher latitudes tend to have greater average foramen magnum lengths. Upon further examination of the scatterplots (Fig.7), the Australian population deviates greatly from the general trend of the data. Out of interest, the data was further explored with this outlier removed; the remaining populations show a strong and significant positive correlation, where northern populations show larger foramen magnum lengths (Fig. 8). This suggests that the Australian population may be skewing the data to inaccurately generate an insignificant result and that the relationship between foramen magnum length and latitude is still worth further exploration. The trend in the data may be a reflection of Bergmann's rule, which suggests increased robusticity in colder climates found in northern populations (Teplitsky & Millien, 2014). Nasal breadth and latitude were also tested for correlation; a significant correlation was not found and the null hypothesis of insignificance cannot be rejected. However, a moderate negative trend can be seen in the scatterplot, reflecting observations in the literature regarding narrow noses being common in cold climates (at higher latitudes) (Fig. 9) (Zaidi et al., 2017).

CONCLUSION

Overall, this study concludes that there is significant variation in both foramen magnum length and nasal breadth across sex and population, proposing that they are sexually dimorphic traits as well as population variants. Although nasal breadth has already been established in the literature to reflect sex and population, this paper reinforces its position as a sexually dimorphic trait that reflects the difference between robust male crania and gracile female crania. Although its correlation is not significant, there appears to be a negative relationship between latitude and nasal breadth, which interestingly does not follow Bergmann's rule of increased size in colder climates, rather following the opposite trend (Teplitsky & Millien, 2014). This suggests that population variation in nasal breadth is related to other factors that can also be linked to latitude, such as humidity, as suggested in the literature (Zaidi et al., 2017). This paper also reinforces nasal breadth as a sexually dimorphic trait, which is also reflective of increased robusticity in male crania in comparison to female crania.

In an attempt to explore a gap in the literature regarding foramen magnum length, its variation across populations was specifically explored, where its population variation was determined to be statistically significant. Although its correlation with latitude was not initially significant, upon further examination and removal of the outlier population of Australia, it showed a strong and significant positive correlation. However, as previously mentioned, this study has its limitations and assumptions; the Howells' dataset, although comprehensive, is limited by its use of skulls from older populations that may not necessarily reflect modern day human variation. Furthermore, this paper only explores seven distinct populations and is not reflective of the total human variation that is present worldwide. The current study has only started the exploration into the value of foramen magnum length in hopes of demonstrating its possible worth in skeletal analysis. Foramen magnum length may have implications for skeletal analysis to assess geographic populations or ancestry in the context of forensic anthropology, bioarchaeology, or biological anthropology. Considering that foramen magnum length has either met or exceeded nasal breadth, an established population variant, in its statistical significance, its potential as a population variant should be further explored in the literature.

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APPENDICES

Appendix 1. Table Depicting Latitudes of Geographic Locations Associated with Population in the Howells' Dataset

Population	Latitude - Degrees Only	Latitude	Notes
Tasmania	-43	43°53'16"S	multiple samples
Lake Alexandrina Tribes, South Australia (Australia)	-35	35°36'14"S	
Yauyos, Peru (South America)	-12	12°26'40"S	multiple samples
Tolai, New Britain (Gazelle Peninsula, Melanesia)	-4	04°38'31"S	
Teita (Voi), Kenya (East Africa)	-3	03°23'33"S	
Andaman Islands	12	12°12'35"N	
Dogon, Mali (West Africa)	14	14°30'N	*provided by Howells
Mokapu, Oahu, Hawaii (Polynesia)	21	21°27'15"N	
Giza, Egypt	29	29°58'05"N	
Early Arikara (North America)	46	46°11'17"N	
Zalavar, Hungary (Central Europe)	46	46°38'16"N	
Berg, Carinthia, Austria (Central Europe)	48	48°05'03"N	
Buriats (Siberia)	51	51°21'46"N	
Oslo, Norway (Northern Europe)	60	60°01'19"N	
Inugsuk Eskimo (Greenland)	62	62°35'33"N	
Zulu (South Africa)		multiple	
Bushman (South Africa)		multiple	

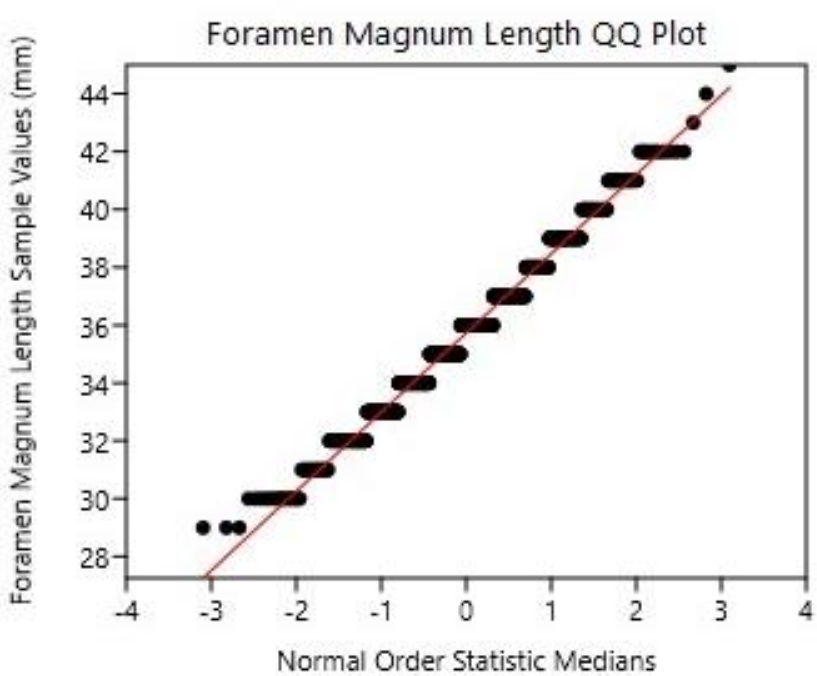
Appendix 2. Summary Statistics of Foramen Magnum Length Based on Sex

	Male	Female
N	363	344
Min	30	29
Max	45	44
Sum	13245	12017
Mean	36.4876	34.93314
Std. error	0.132434	0.146416
Variance	6.366559	7.374525
Stand. dev	2.523204	2.715608
Median	36	35
25 prcntil	35	33
75 prcntil	38	37
Skewness	0.186332	0.312555
Kurtosis	-0.04708	-0.10151
Geom. mea	36.40085	34.82887
Coeff. var	6.915236	7.773729

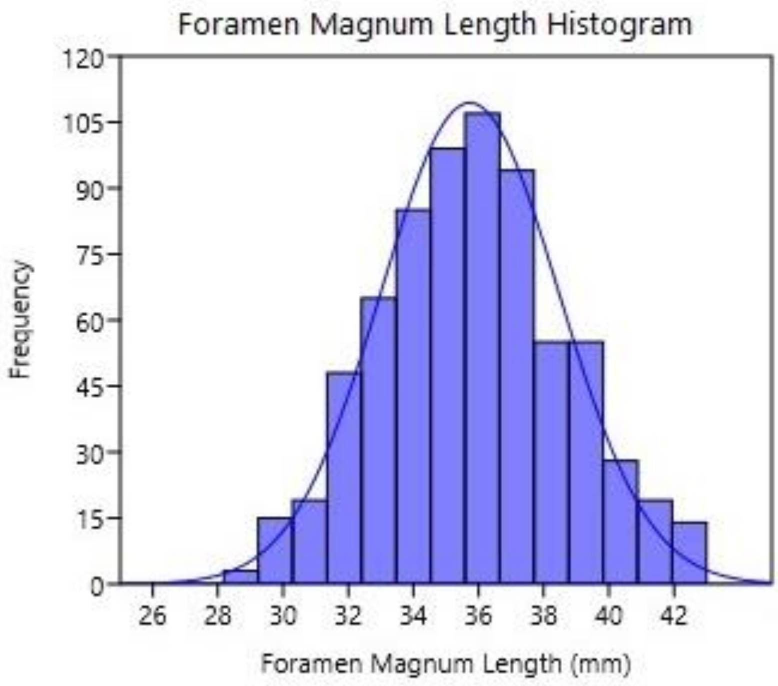
Appendix 3. Summary Statistics of Foramen Magnum Length Based on Population

	EGYPT	DOGON	AUSTRALI	TOLAI	BURIAT	ESKIMO	ARIKARA
N	111	99	101	110	109	108	69
Min	30	29	32	29	30	33	32
Max	42	42	42	39	44	45	42
Sum	3866	3375	3631	3745	3994	4104	2547
Mean	34.82883	34.09091	35.9505	34.04545	36.6422	38	36.91304
Std. error	0.2129601	0.264778	0.2074724	0.2242163	0.2267091	0.2189531	0.296857
Variance	5.03407	6.940631	4.347525	5.530025	5.602277	5.17757	6.080563
Stand. dev	2.243673	2.634508	2.085072	2.351601	2.366913	2.275427	2.46588
Median	35	34	36	34	37	38	37
25 prcntil	33	32	34.5	32	35	36	35
75 prcntil	36	36	37	36	38	40	39
Skewness	0.6408902	0.5248042	0.05354791	0.05230506	0.2627984	0.3346151	0.0665727
Kurtosis	0.8665801	0.1461502	-0.05507833	-0.644192	0.319606	-0.257754	-0.5989607
Geom. mean	34.7587	33.9921	35.89052	33.96482	36.56688	37.93314	36.83178
Coeff. var	6.442001	7.727889	5.799842	6.907238	6.459527	5.987967	6.680239

Appendix 4. QQ Plot Assessing Normality of Foramen Magnum Length



Appendix 5. Histogram Assessing Normality of Foramen Magnum Length



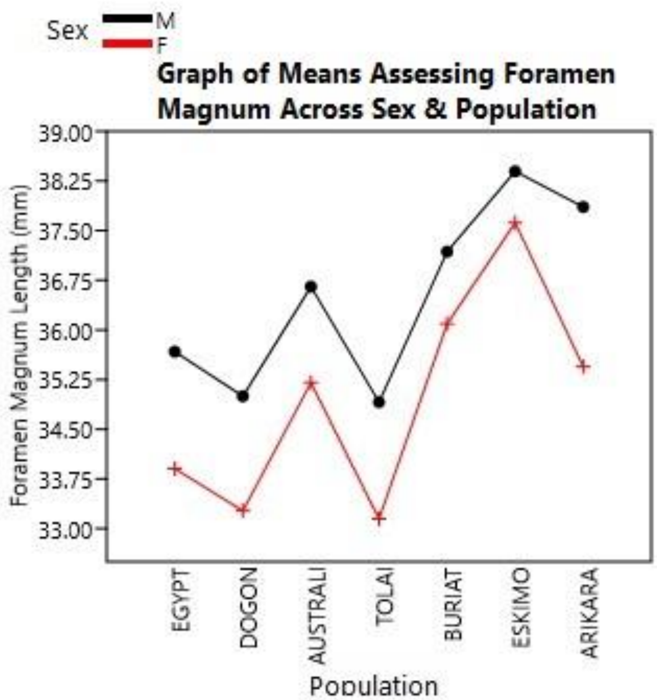
Appendix 6. Two-Way ANOVA Assessing Significance of Variation in Foramen Length Across Sex and Population.

Variable(s)	Sum of Squares	Degrees of Freedom	Mean Square	*F*	*p* (same)
Sex	426.783	1	426.783	86.97	1.45E-19
Population	1416.96	6	236.16	48.12	2.05E-49
Interaction	39.81	6	6.63499	1.352	0.2317
Within	3400.82	693	4.90739		
Total	5260.94	706			

Appendix 7. Tukey's Pairwise Post-Hoc Test Assessing Statistically Significant Pairs of Mean Foramen Magnum Lengths

First Population in Pair	Second Population in Pair	Q	p
M-DOGON	M-ESKIMO	10.83	0
M-TOLAI	M-ESKIMO	11.61	0
F-EGYPT	F-ESKIMO	12.31	0
F-DOGON	F-ESKIMO	14.36	0
F-TOLAI	F-BURIAT	9.767	0
F-TOLAI	F-ESKIMO	14.9	0
F-DOGON	F-BURIAT	9.278	2.45E-09
M-TOLAI	M-ARIKARA	9.263	2.78E-09
M-EGYPT	M-ESKIMO	9.155	5.85E-09
M-DOGON	M-ARIKARA	8.597	8.73E-08
F-AUSTRALI	F-ESKIMO	7.852	1.79E-06
M-TOLAI	M-BURIAT	7.637	4.06E-06
F-EGYPT	F-BURIAT	7.221	1.88E-05
M-DOGON	M-BURIAT	7.023	3.77E-05
M-EGYPT	M-ARIKARA	6.929	5.23E-05
F-AUSTRALI	F-TOLAI	6.656	0.0001313
F-TOLAI	F-ARIKARA	6.405	0.0002969
M-ARIKARA	F-ARIKARA	6.32	0.0003888
F-DOGON	F-AUSTRALI	6.205	0.0005563
F-ESKIMO	F-ARIKARA	6.091	0.0007888
F-DOGON	F-ARIKARA	6.011	0.001006
M-EGYPT	F-EGYPT	5.938	0.001247
M-TOLAI	F-TOLAI	5.9	0.001395
M-AUSTRALI	M-TOLAI	5.78	0.001976
M-AUSTRALI	M-ESKIMO	5.699	0.002492
M-DOGON	F-DOGON	5.493	0.004403
M-DOGON	M-AUSTRALI	5.249	0.0084
M-EGYPT	M-BURIAT	5.121	0.01164
F-BURIAT	F-ESKIMO	5.084	0.01275
M-AUSTRALI	F-AUSTRALI	4.65	0.03533
F-EGYPT	F-ARIKARA	4.272	0.07765
F-EGYPT	F-AUSTRALI	4.184	0.09203
M-BURIAT	M-ESKIMO	4.028	0.1227
M-AUSTRALI	M-ARIKARA	3.713	0.2076
M-BURIAT	F-BURIAT	3.63	0.2356
M-EGYPT	M-AUSTRALI	3.283	0.3762
F-AUSTRALI	F-BURIAT	2.877	0.5751
M-EGYPT	M-TOLAI	2.596	0.7123
M-ESKIMO	F-ESKIMO	2.581	0.7193
F-EGYPT	F-TOLAI	2.501	0.7549
M-EGYPT	M-DOGON	2.193	0.8708
M-BURIAT	M-ARIKARA	2.113	0.8943
F-EGYPT	F-DOGON	2.082	0.9029
F-BURIAT	F-ARIKARA	1.808	0.9582
M-AUSTRALI	M-BURIAT	1.743	0.967
M-ESKIMO	M-ARIKARA	1.672	0.975
M-DOGON	M-TOLAI	0.2887	1
F-DOGON	F-TOLAI	0.3979	1
F-AUSTRALI	F-ARIKARA	0.6544	1

Appendix 8. Graphs of Means Assessing Significance of Variation in Foramen Magnum Length Across Sex and Population.



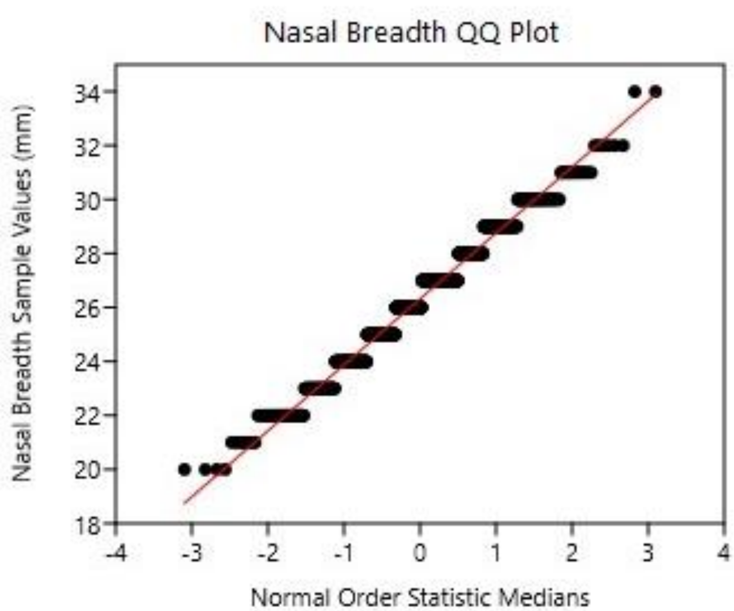
Appendix 9. Summary Statistics of Nasal Breadth Based on Sex

	M	F
N	363	344
Min	20	20
Max	34	32
Sum	9736	8872
Mean	26.82094	25.7907
Std. error	0.1327973	0.11957
Variance	6.401549	4.918164
Stand. dev	2.530128	2.217693
Median	27	26
25 prcntil	25	24
75 prcntil	29	27
Skewness	-0.1605327	0.02752889
Kurtosis	-0.2451735	-0.4624113
Geom. mean	26.69949	25.69506
Coeff. var	9.433408	8.598811

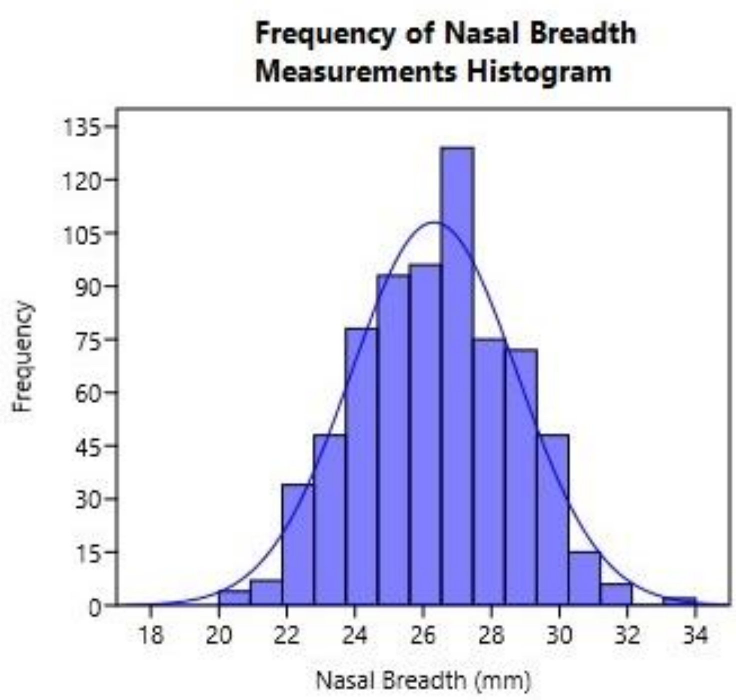
Appendix 10. Summary Statistics of Nasal Breadth Based on Population

	EGYPT	DOGON	AUSTRALI	TOLAI	BURIAT	ESKIMO	ARIKARA
N	111	99	101	110	109	108	69
Min	21	25	23	23	22	20	23
Max	29	32	34	32	34	29	31
Sum	2713	2776	2736	2997	3013	2538	1835
Mean	24.44144	28.0404	27.08911	27.24545	27.6422	23.5	26.5942
Std. error	0.1586618	0.1692254	0.1808117	0.1804389	0.2042377	0.156491	0.2158656
Variance	2.794267	2.835086	3.30198	3.581401	4.546721	2.64486	3.21526
Stand. dev	1.671606	1.683771	1.817135	1.892459	2.132304	1.626302	1.793115
Median	24	28	27	27	27	23.5	27
25 prcntil	23	27	26	26	26	22	25
75 prcntil	25	29	28	29	29	25	27.5
Skewness	0.4606043	0.2886694	0.3037711	0.1432682	0.0710988	0.2390859	0.3225249
Kurtosis	0.08759633	-0.5972901	1.20816	-0.4925734	0.1376853	0.5749468	-0.3846883
Geom. mean	24.38565	27.99077	27.02912	27.18045	27.56039	23.44447	26.5352
Coeff. var	6.839229	6.004804	6.707992	6.945962	7.713945	6.920436	6.742502

Appendix 11. QQ Plot Assessing Normality of Nasal Breadth



Appendix 12. Histogram Assessing Normality of Nasal Breadth



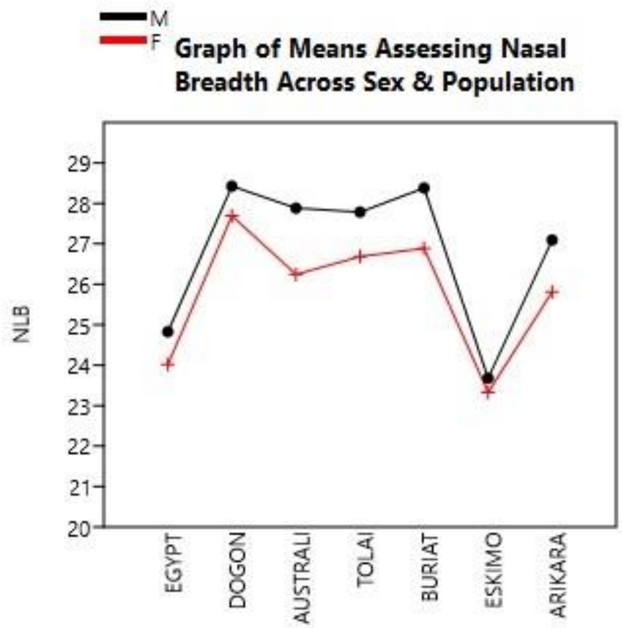
Appendix 13. Two-Way ANOVA Assessing Significance of Variation in Nasal Breadth Across Sex and Population.

	Sum of Squares	Degrees of Freedom	Mean Square	F	p (same)
Sex	187.466	1	187.466	62.61	9.98E-15
Population	1893.29	6	315.549	105.4	3.72E-94
Interaction	33.2248	6	5.53747	1.849	0.08713
Within	2074.93	693	2.99413		
Total	4191.76	706			

Appendix 14. Tukey's Pairwise Post-Hoc Test Assessing Statistically Significant Pairs of Mean Nasal Breadths

First Population in Pair	Second Population in Pair	Q	p
M-EGYPT	M-DOGON	15.02	0
M-EGYPT	M-AUSTRALI	13.09	0
M-EGYPT	M-TOLAI	12.91	0
M-EGYPT	M-BURIAT	15.44	0
M-DOGON	M-ESKIMO	19.38	0
M-AUSTRALI	M-ESKIMO	17.61	0
M-TOLAI	M-ESKIMO	17.52	0
M-BURIAT	M-ESKIMO	19.97	0
M-ESKIMO	M-ARIKARA	13.56	0
F-EGYPT	F-DOGON	15.38	0
F-EGYPT	F-TOLAI	11.27	0
F-EGYPT	F-BURIAT	12.13	0
F-DOGON	F-ESKIMO	18.45	0
F-AUSTRALI	F-ESKIMO	12.15	0
F-TOLAI	F-ESKIMO	14.33	0
F-BURIAT	F-ESKIMO	15.2	0
M-EGYPT	M-ARIKARA	9.207	4.20E-09
F-EGYPT	F-AUSTRALI	9.184	4.90E-09
F-ESKIMO	F-ARIKARA	8.924	2.00E-08
M-AUSTRALI	F-AUSTRALI	6.733	0.0001018
F-DOGON	F-ARIKARA	6.642	0.0001377
F-EGYPT	F-ARIKARA	6.384	0.0003181
M-BURIAT	F-BURIAT	6.369	0.0003329
F-DOGON	F-AUSTRALI	5.943	0.00123
M-BURIAT	M-ARIKARA	5.155	0.01069
M-DOGON	M-ARIKARA	5.124	0.01153
M-EGYPT	M-ESKIMO	4.942	0.01804
M-TOLAI	F-TOLAI	4.716	0.03044
M-ARIKARA	F-ARIKARA	4.294	0.07439
F-DOGON	F-TOLAI	4.237	0.08319
F-BURIAT	F-ARIKARA	3.836	0.1707
M-EGYPT	F-EGYPT	3.48	0.2918
F-DOGON	F-BURIAT	3.38	0.3334
M-AUSTRALI	M-ARIKARA	3.119	0.4541
F-TOLAI	F-ARIKARA	3.108	0.4592
M-DOGON	F-DOGON	2.979	0.5233
F-EGYPT	F-ESKIMO	2.937	0.5447
M-TOLAI	M-ARIKARA	2.779	0.6241
F-AUSTRALI	F-BURIAT	2.669	0.6777
M-DOGON	M-TOLAI	2.648	0.6876
M-TOLAI	M-BURIAT	2.566	0.7258
M-DOGON	M-AUSTRALI	2.198	0.8694
M-AUSTRALI	M-BURIAT	2.101	0.8976
F-AUSTRALI	F-TOLAI	1.825	0.9557
F-AUSTRALI	F-ARIKARA	1.499	0.9882
M-ESKIMO	F-ESKIMO	1.495	0.9884
F-TOLAI	F-BURIAT	0.8651	0.9998
M-DOGON	M-BURIAT	0.1801	1
M-AUSTRALI	M-TOLAI	0.4199	1

Appendix 15. Graphs of Means Assessing Significance of Variation in Nasal Breadth Across Sex and Population.



Appendix 16. Table Containing Mean (Average) Foramen Magnum Length & Nasal Breadth for Each Population

	Foramen Magnum Length (mm)	Nasal Breadth (mm)
EGYPT	34.82882883	24.44144144
DOGON	34.09090909	28.04040404
AUSTRALI	35.95049505	27.08910891
TOLAI	34.04545455	27.24545455
BURIAT	36.64220183	27.64220183
ESKIMO	38	23.5
ARIKARA	36.91304348	26.5942029

Appendix 17. Summary Statistics of Mean (Average) Foramen Magnum Length & Nasal Breadth by Population

	Foramen Magnum Length	Nasal Breadth
N	7	7
Min	34.04545	23.5
Max	38	28.0404
Sum	250.4709	184.5528
Mean	35.78156	26.36469
Std. error	0.5721936	0.6491495
Variance	2.291839	2.949765
Stand. dev	1.513882	1.717488
Median	35.9505	27.08911
25 prcntil	34.09091	24.44144
75 prcntil	36.91304	27.6422
Skewness	0.139809	-1.04811
Kurtosis	-1.447432	-0.4413214
Geom. mean	35.75416	26.31503
Coeff. var	4.2309	6.51435

Appendix 18. Table Containing Mean (Average) Foramen Magnum Length & Nasal Breadth for Each Sex & Population (Combined)

	Foramen Magnum Length (mm)	Nasal Breadth (mm)
F ARIKARA	35.2962963	24.59259259
F AUSTRALI	35.34693878	24.53061224
F BURIAT	34.09259259	25.61111111
F DOGON	34.34615385	28.13461538
F EGYPT	34.9245283	27.62264151
F ESKIMO	35.8	27.21818182
F TOLAI	34.74074074	27.14814815
M ARIKARA	34.33333333	27.38095238
M AUSTRALI	34.71153846	27.30769231
M BURIAT	36.92727273	27.89090909
M DOGON	36.46808511	26.06382979
M EGYPT	38.32758621	23.60344828
M ESKIMO	37.49056604	24.24528302
M TOLAI	36.64285714	26.53571429

Appendix 19. Summary Statistics of Mean (Average) Foramen Magnum Length & Nasal Breadth by Sex & Population (Combined)

	Foramen Magnum Length	Nasal Breadth
N	14	14
Min	34.09259	23.60345
Max	38.32759	28.13462
Sum	499.4485	367.8857
Mean	35.67489	26.27755
Std. error	0.3489962	0.4026736
Variance	1.705177	2.270044
Stand. dev	1.305824	1.506667
Median	35.32162	26.84193
25 prcntil	34.62019	24.5771
75 prcntil	36.71396	27.44137
Skewness	0.6884387	-0.5497928
Kurtosis	-0.5279121	-1.188748
Geom. mean	35.653	26.23664
Coeff. var	3.660345	5.733664

Appendix 20. Table Containing Mean (Average) Foramen Magnum Length & Population Latitude

	Foramen Magnum Length (mm)	Latitude
AUSTRALI	36.04950495	-35
TOLAI	34.1	-4
DOGON	34.1010101	14
EGYPT	34.82882883	29
ARIKARA	36.98550725	46
BURIAT	36.69724771	51
ESKIMO	37.99074074	62

Appendix 21. Summary Statistics of Mean (Average) Foramen Magnum Length & Population Latitude

	Foramen Magnum Length	Latitude
N	7	7
Min	34.1	-35
Max	37.99074	62
Sum	250.7528	163
Mean	35.82183	23.28571
Std. error	0.5729722	12.94993
Variance	2.29808	1173.905
Stand. dev	1.515942	34.26229
Median	36.0495	29
25 prcntil	34.10101	-4
75 prcntil	36.98551	51
Skewness	0.08584132	-0.742033
Kurtosis	-1.592961	-0.250451
Geom. mean	35.79436	0
Coeff. var	4.231894	147.1387

Appendix 22. Table Containing Mean (Average) Nasal Breadth & Population Latitude

	Latitude	Nasal Breadth (mm)
AUSTRALI	-35	27.11881188
TOLAI	-4	27.27272727
DOGON	14	28.02020202
EGYPT	29	24.61261261
ARIKARA	46	26.50724638
BURIAT	51	27.6146789
ESKIMO	62	23.49074074

Appendix 23. Summary Statistics of Mean (Average) Nasal Breadth & Population Latitude

	Latitude	Nasal Breadth (mm)
N	7	7
Min	-35	23.49074
Max	62	28.0202
Sum	163	184.637
Mean	23.28571	26.37672
Std. error	12.94993	0.6370522
Variance	1173.905	2.840849
Stand. dev	34.26229	1.685482
Median	29	27.11881
25 prcntil	-4	24.61261
75 prcntil	51	27.61468
Skewness	-0.742033	-1.075018
Kurtosis	-0.250451	-0.2162061
Geom. mean	0	26.3289
Coeff. var	147.1387	6.390036