DETERMINING SEX AND ANCESTRY OF THE HYOID FROM THE ROBERT J. TERRY ANATOMICAL COLLECTION

by

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ABSTRACT

One of the basic goals of the physical anthropologist is to create a biological profile, consisting of sex, ancestry, age, and stature, from the skeletal material that they are presented with. This thesis seeks to explore size and shape differences related to sex and ancestry from the hyoid bones of the Robert J. Terry Anatomical Collection in order to gauge its usefulness in the process of developing a biological profile. A series of measurements were taken from 398 hyoids and analysis was conducted using a number of statistical methods. Independent samples *t*-tests were used to examine size differences between sexes and ancestries, while linear regression analysis and principle component analysis were used to examine shape differences. Discriminant function analysis was employed to test the ability of the hyoids to be classified by sex or ancestry. The ultimate goal of the thesis is to provide physical anthropologists with a series of discriminant function equations that can be used to estimate the sex and ancestry of a hyoid. Five equations ranging in accuracy from 83-88% were developed to determine sex of a hyoid, while four equations ranging in accuracy from 70-89% can be used to determine ancestry. In addition, the *t*-tests, regression analyses, and principle component analysis have identified several variations in size and shape between sexes and ancestries. These analyses have provided further knowledge as to the morphological form of the hyoid, as well as a method that can be easily used by physical anthropologists to assess sex and ancestry.

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Dedicated to Jeff, Mary, and Hilly

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CHAPTER ONE: INTRODUCTION

During the process of developing a biological profile for unidentified skeletal material, possibly the least likely bone to be used is the hyoid, a small horseshoe-shaped bone positioned in the anterior, upper neck (Papadopoulos et al., 1989; Ubelaker, 1990). Although the hyoid has gained notoriety within forensic anthropology for possibly indicating hanging or strangulation (Ubelaker, 1992), its usefulness in aiding the anthropologist in their estimation of sex and, in particular, ancestry has been somewhat neglected. Several studies focusing on size and shape differences between sexes (Miller et al., 1998; Reesink et al., 1999; Lekšan et al., 2005; Kim et al., 2006) have used a variety of statistical methods, primarily discriminant function analysis, to attempt to produce standards that can then be used to estimate sex of a recovered hyoid. However, the previously mentioned studies are primarily focused on articulated hyoids and only one study (Kim et al., 2006) has approached the subject of ancestral differences in the hyoid. This study has the ability to fill in the blanks of hyoid research, namely the lack of focus on the disarticulated hyoid and variation due to ancestral differences.

The goal of this study is to further explore the unique size and shape characteristics of the hyoid in an attempt to evaluate its usefulness in determining sex and ancestry. Two major differences that set this study apart from others are the inclusion of disarticulated hyoids in the sample population and the focus on differences between ancestral populations. In an ideal situation, a hyoid recovered from an archaeological or forensic site will be articulated and undamaged whereas in reality, skeletal remains are rarely recovered in their ideal condition. Therefore it is important to include hyoids which are fully disarticulated or unilaterally articulated so that if a disarticulated hyoid is recovered it can also be used to estimate sex and ancestry. The inclusion of disarticulated hyoids in the sample also allows the opportunity to statistically examine their size and shape properties independent of articulated hyoids, creating the opportunity to develop discriminant functions for both disarticulated and articulated hyoids. This is also one of the first studies with a focus on ancestral differences in the hyoid and its possible value to ancestry estimation. Because ancestry determination is one of the most difficult components of the biological profile to perform it is imperative that new methods are continually developed and tested, particularly metric methods that can be used by even inexperienced individuals.

Chapters two and three of this thesis utilize a number of statistical procedures to examine variation between sexes and hyoids of African and European ancestries, respectively. The primary goal of both chapters is to use discriminant function analysis (DFA) to produce a series of equations which can then be used by physical anthropologists to estimate sex and ancestry of a hyoid while building a biological profile. However, despite the focus on sex and ancestry determination using DFA, the thesis also includes the use of statistical methods to further explore variation in size and shape of the hyoid, particularly between two populations of different ancestral backgrounds, so as to learn more about the morphology of the bone.

When determining sex and ancestry of skeletal material, the physical anthropologist often has a choice between using morphological indicators or metric methods, depending upon the elements available for analysis and their condition. Although the use of morphological traits has traditionally been preferred over metric methods (Hefner, 2007), many researchers prefer metric methods due to their precision (Kim et al., 2006) and ability to explore the data statistically. Although studies examining morphological differences in hyoid shape between sexes have been conducted (Papadopoulos et al., 1989; Pollanen and Ubelaker, 1997; Miller et al., 1998; Lekšan et al., 2005), statistical methods were chosen to demonstrate shape differences due to the difficulty of assigning a shape to a hyoid and also to allow the inclusion of disarticulated hyoids in the study.

Chapter two presents a number of statistical tests used to establish the presence of sexual dimorphism within the sample and also explore shape differences which may be present at the measurement sites. Independent samples *t*-tests were used to analyze the size differences between males and females of each measurement to determine whether the difference is statistically significant. These tests were used to confirm the presence of sexual dimorphism within the sample and also determine which components of the bone were the most sexually dimorphic. Linear regression analysis was then used to identify which measurements taken on both articulated and disarticulated hyoids exhibited shape differences. This method allowed both articulated and disarticulated hyoids to be examined and the results analyzed for similarities between the two groups.

Chapter two also presents a series of four discriminant functions that provide the physical anthropologist with the ability to estimate the sex of both articulated and disarticulated hyoids. One function was developed for each using only the articulated and disarticulated hyoid samples while the other two were created using all 398 hyoids. Creating four rather than one or two functions allows them to be used in conjunction with each other so that multiple sex estimations can be made of the same bone. It is believed that this will increase the accuracy of the sex estimation. Chapter two concludes with a discussion of how to use the functions, a comparison of the functions produced in this study with commonly used sex determination methods, and past research dealing with hyoid shape.

Chapter three examines a relatively unexplored area of hyoid research by studying size and shape differences between samples of African and European hyoids in the Terry Collection. Previous to this study, the only published research addressing hyoid differences between ancestries is by Kim and colleagues (2006) who, in their article which was mainly focused on sex differences, compared the average of their measurements to those of a previous study by Miller and colleagues (1998). The study compared two populations from Korea and North America, composed of Asian and White/Hispanic individuals, respectively. Kim and colleagues (2006) concluded that, based on the differences of the measurements between each sample, they believe the hyoid can be used as an indicator of ancestral affiliation.

Independent samples *t*-tests were conducted to test for size differences between the two ancestries at the site of each measurement and to determine whether any differences were statistically significant. These tests were used to test for the presence of dimorphism within the sample and also determine which, if any, components of the bone were the most dimorphic. Two statistical methods were used to test for shape differences. Linear regression analysis was used to determine whether shape differences occurred at the measurement sites, once again allowing for both articulated and disarticulated hyoids to be analyzed. In addition, principle component analysis (PCA) was used as a hypothesis-building tool to suggest what shape components contribute the most to the variation in shape between ancestries. The PCA also demonstrates how much of the variation between hyoids of African and European ancestries is due to size and how much is due to shape.

As in chapter two, chapter three presents a series of three discriminant functions that have the ability to aid the physical anthropologist in estimating the ancestry of both articulated and disarticulated hyoids. One function each was developed using only the articulated and disarticulated hyoid samples while the third function was created using all 200 hyoids used in this sample. Creating three rather than one or two functions allows them to be used in conjunction with each other so that multiple ancestry estimations can be made of the same bone. It is believed that this will increase the accuracy of the ancestry determination. Chapter three concludes with a discussion of how to use the functions in conjunction with one another and a comparison of the functions produced in this study with commonly used ancestry determination methods. The chapter also includes a discussion of the shape variation that is seen using regression analysis and PCA with suggestions as to why we may see this variation.

The overall goal of this thesis is to present the hyoid as a bone which has the ability to be used in building the biological profile of an individual. The statistical methods used in this study indicate clear differences in size and shape between sexes and ancestries which can then be used to distinguish them from one another. The discriminant function analyses also provide evidence that it is possible to discriminate males and females and African and European hyoids, and the functions produced by this method can be used by physical anthropologists to estimate sex and ancestry of a recovered hyoid. This study provides evidence that the hyoid can be useful to the physical anthropologist in more ways than just indicating strangulation.

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CHAPTER TWO: DETERMINING SEX OF THE HYOID FROM THE TERRY COLLECTION USING DISCRIMINANT FUNCTION ANALYSIS

Introduction

The hyoid is generally one of the least represented bones in forensic and archaeological settings involving skeletal remains due to its small size and the possibility that it will be found disarticulated into multiple elements. These factors make it difficult to locate a complete hyoid in both contexts, particularly if the site has been disturbed. However, previous research (Jelisiejew et al., 1968; Miller et al., 1998; Reesink et al., 1999; Kim et al., 2006) has shown that the hyoid is a sexually dimorphic bone and therefore has the ability to aid the physical anthropologist in the determination of sex.

Sex is one of the four defining characteristics of the biological profile that a physical anthropologist constructs when dealing with unidentified skeletal remains and is generally predicted using elements such as the pubic bone or cranium (see Giles and Elliot, 1963; Phenice, 1969). While these are certainly the most preferred elements to use in sex determination, often only a small assemblage of bones is recovered and as a result it is important to develop sexing techniques for as many bones of the body as possible. This study has three main goals regarding sexual dimorphism of the hyoid. The first is to establish the presence of sexual dimorphism in the Robert J. Terry Anatomical Collection, the second is to metrically test differences in shape between male and female hyoids, and the third is to develop a series of discriminant functions that can be used to classify a hyoid as male or female.

The majority of hyoid studies take their measurements from digital imagery, namely radiographs (Jelisiejew et al., 1968) or digital photographs (Kim et al., 2006). This study differs significantly from others using similar analytical methods in that the measurements were performed on the actual bone using standard osteometric calipers. Using the methods utilized in this study allows the measurements to be easily replicated without needing to take an image of the bone and then take the measurements using some form of a computer program. This is also one of the only studies to use the hyoids from a documented anatomical collection rather than hyoids obtained during autopsy. Although the specimens from the Terry Collection may exhibit differential preservation due to handling and the curation process, using specimens that have been macerated and skeletonized has allowed for the measurement of articulated as well as disarticulated hyoids, which is more likely to replicate forensic or archaeological situations. This allows for statistical analysis of the size and shape of both articulated and disarticulated hyoids in relation to sex.

At the core of this project is the concept of sexual dimorphism, or the basic idea that males and females exhibit differences in size and shape (Mielke et al., 2006). It has been well established within osteological and paleoanthropological research that sexual dimorphism has been present throughout human evolution as well as in modern populations (Frayer and Wolpoff, 1985). Although the level of dimorphism found between modern human males and females is considerably less than their ancestors (Frayer and Wolpoff, 1985), it is still prominent enough to allow physical anthropologists to develop numerous methods of determining sex of an individual based on skeletal material.

Because humans are essentially osteologically similar prior to puberty, the most likely cause of the difference of size and shape between sexes is hormonal influence (Beach, 1978) and as hormones are released over a period of time the skeleton begins to take its adult form. Until this time male and female skeletons are for the most part indistinguishable, making juvenile skeletal remains nearly impossible to sex (Scheuer and Black, 2000). Jelisiejew and colleagues (1968) studied the shape and size of a number of adolescent hyoids and showed that, as can be expected, the size of the hyoid increases with age and until about the age of 16 remains very similar between males and females. Differences in the mean size between sexes begins to appear between the ages of 16 and 20 years and after that age males grew more quickly (Jelisiejew et al., 1968). This study suggests that the hyoid follows the patterns of growth and morphological development that have been accepted to be the reason behind sexual dimorphism.

Sex determination, like all other elements of the biological profile, should be made using as many skeletal elements and methods as possible. This study proposes an additional method utilizing several hyoid measurements to provide sex estimation. This method can then be used in addition to other sexing methods in helping the physical anthropologist classify the individual as male or female.

Materials

All hyoids utilized in this study are part of the Robert J. Terry Anatomical Collection, housed at the Smithsonian Institute's National Museum of Natural History (NMNH) in Washington, D.C. The Terry Collection was started in 1898 by Robert J. Terry at the Missouri Medical College, later becoming part of Washington University Medical School (Hunt and Albanese, 2005). The skeletons were collected from cadavers used in the medical school's anatomy classes and were originally obtained primarily from local St. Louis hospitals and institutional morgues, with a smaller number coming from other institutions around the state of Missouri. The majority of the cadavers were individuals who were not claimed by relatives at local morgues and became property of the state (Hunt and Albanese, 2005). As a result these cadavers usually represented the St. Louis and Missouri lower socioeconomic class. Varying documentation accompanies each skeleton. All individuals have some form of a morgue record that includes basic information such as name, sex, age at death, "race," cause of death, and date of death (Hunt and Albanese, 2005). Most skeletons also include documentation such as dental charts and inventory lists. Currently the Terry Collection consists of 1,728 specimens, 1,607 of which have had their age confirmed and sex and "race" recorded on the morgue record (Hunt and Albanese, 2005).

Of the 1,607 specimens whose age, sex, and "race" have been confirmed, a total of 398 hyoids (200 males and 198 females) were measured for this study. Of these, 169 hyoids were fully articulated with both greater cornua fused to the hyoid body, and 229 were disarticulated hyoids in which only one or none of the greater cornua were fused to the body. Figure 1 represents the composition of the sample population in terms of sex, age, and whether the hyoid is articulated or disarticulated.

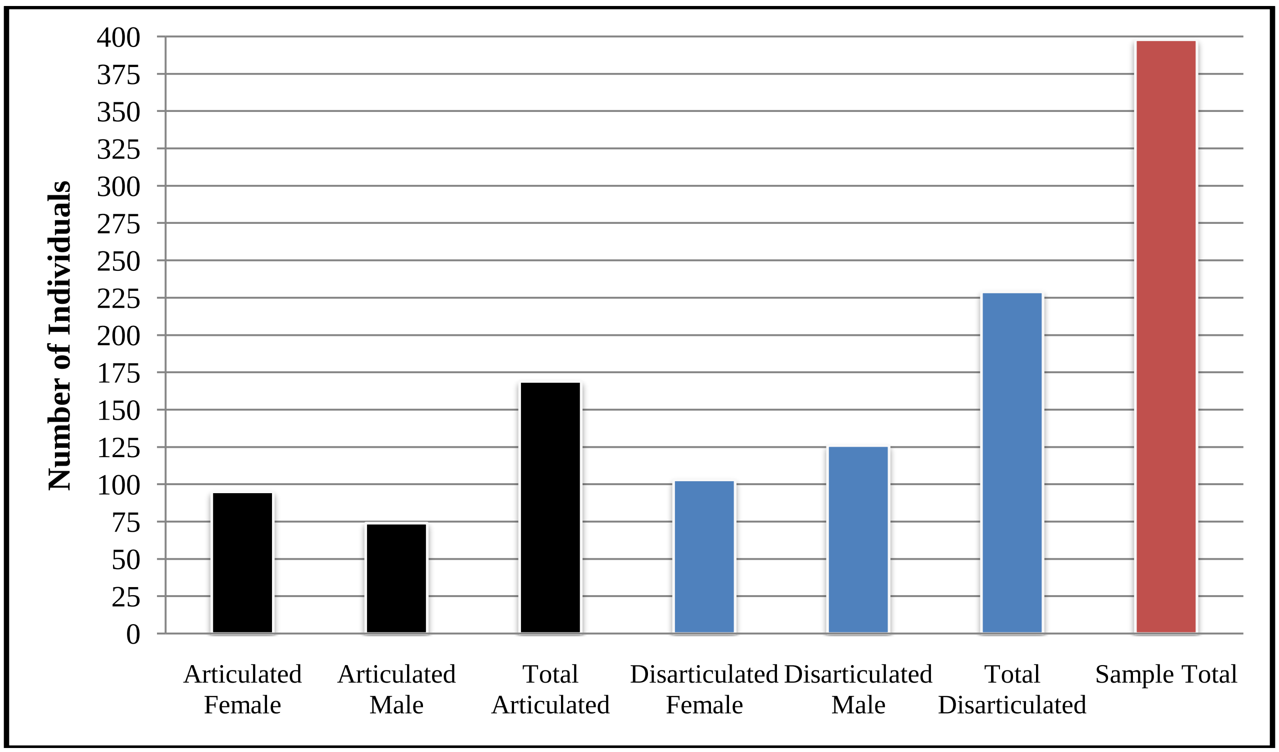

Figure 1. A breakdown of the demographics of the study sample by sex, and whether the hyoid is articulated or disarticulated

Methods

In an attempt to develop a sampling population that was as uniform as possible, the collection was divided by age, sex, and race. Individuals between the ages of 20 and 79 were broken into groups delineated by 10 year increments, and within these age groups an attempt was made to obtain 20 hyoids from both black and white males and females within that range. Unfortunately, some groups within the Terry Collection are underrepresented, namely white females below the age of 40, so that less than 20 hyoids were recovered from individuals within those ranges. However, because this study is focused on sex rather than age or ancestry, if one sex was more underrepresented than the other toward the end of the data collection process, that sex was focused on in an attempt to even the sample numbers of males and females.

To streamline the data collection process, two sets of measurements were developed to be applied to both the articulated and disarticulated hyoid. Each measurement was chosen due to its use in previous research (Jelisiejew et al., 1968; Miller et al., 1998; Reesink et al., 1999; Lekšan et al., 2005; Shimizu et al., 2005; Kim et al., 2006) and the demonstration by this research that most, if not all, of the measurement sites displayed sexual dimorphism. It was also important to gain an overall view of the size and shape of each component of the hyoid and it was believed that these measurements would be able to accomplish this. These measurements, outlined in Tables 1 and 2, were taken using standard osteometric calipers (Figures 2 and 3). Because it was believed prior to data collection that the preservation of the hyoids would be variable, resulting in the inability to take some measurements, both the right and left sides of each hyoid was measured to maximize the amount of data that would be available for analysis.

Table 1. Articulated hyoid measurements.

Measurement	Description
1	Total hyoid length
2	Total hyoid width
3	Maximum length of body
4	Maximum height of body
5	Distance between the distal ends of the right and left greater cornua-taken from lateral edges
6, 7	Width of greater cornua at articulation point with body – Right and left
8, 9	Height of greater cornua at articulation point with body – Right and left
10, 11	Maximum length of greater cornua – Left and right
12, 13	Greatest width of distal end of greater cornua – Left and right
14, 15	Greatest height of distal end of greater cornua – Right and left

Figure 2. Articulated hyoid measurements (NMNH Terry Collection #561).

Table 2. Disarticulated hyoid measurements.

Measurement	**Description**
1	Maximum length of body
2	Maximum height of body
3, 4	Width of greater cornua articulation point with body – Right and left
5, 6	Height of greater cornua at articulation point with body – Right and left
7, 8	Maximum length of greater cornua – Left and right
9, 10	Greatest width of the distal end of the greater cornua – Left and right
11, 12	Greatest height of the distal end of the greater cornua – Right and left

Figure 3. Disarticulated hyoid measurements (NMNH Terry Collection #908).

All statistical tests were run using SPSS 17.0. Two statistical methods were used to determine differences in the size and shape of the hyoid between males and females. First, independent samples *t*-tests were used to determine whether differences in size between males and females were significant and *p*-values below 0.05 were taken to indicate a statistically significant difference in size between males and females, supporting the hypothesis that sexual dimorphism is present in the sample. Second, skeletal measurements were regressed on the geometric mean, which is the sum of all skeletal measurements divided by the total number of measurements, using Least Squares linear regression. This way, when linear regression analysis was applied to each hyoid the residuals indicated differences in shape rather than differences in size. Negative residuals suggested that the measurement is relatively smaller in shape rather than size than the same measurement resulting in positive residuals. Independent samples *t*-tests were then performed using the residuals of each measurement for males and females to test whether the differences in shape were statistically significant.

Discriminant function analysis was performed in an attempt to develop discriminant functions utilizing a combination of measurements that would have the ability to classify a hyoid as either male or female. In developing the discriminant functions, the significance of each independent variable, or measurement, in the discriminant function analysis was determined using stepwise statistics to find the variables which set the Wilk's lambda at a minimum. The distinction ability of the discriminant function analysis was evaluated by looking at the canonical correlation and eigenvalues so that the higher the canonical correlation and the closer the eigenvalue is to one, the higher the discrimination ability of the function (Kim et al., 2006). The eigenvalue reflects the ratio of importance of the dimensions, in this case the measurements, which classify cases of the dependent variable, or sex and is calculated by dividing the "variance within groups" by the "variance between groups" (Kim et al., 2006).

Results

A One-Sample Kolmogorov-Smirnov Test was run for both articulated and disarticulated hyoids to determine whether the data was distributed normally. The test confirmed that the data is distributed normally and therefore, parametric statistical methods, including discriminant function analysis and independent samples *t*-tests, were used in this analysis.

Independent Samples t-test Results

Independent samples *t*-tests were run using all measurements of articulated and disarticulated hyoids to test for differences in size between males and females for each measurement. *t*-tests performed using the articulated hyoid measurements show statistically significant differences in size between males and females for all but two measurements (Table 3). Those measurements that do not exhibit significant differences are the width and height of the distal ends of the left greater cornua.

Table 3. Average measurements (mm) and p-values of articulated hyoids.

Measurement	**Males**	**Females**	***p* -Value**
Total hyoid length	37.60 ± 3.62	33.02 ± 3.62	0.000
Total hyoid width	42.25 ± 4.36	38.33 ± 4.60	0.000
Maximum length of body	24.12 ± 2.34	20.86 ± 2.54	0.000
Maximum height of body	12.13 ± 1.17	10.72 ± 1.24	0.000
Maximum length of greater cornua, Right	31.07 ± 3.2	27.47 ± 3.4	0.000
Maximum length of greater cornua, Left	30.51 ± 3.3	27.2 ± 3.1	0.001
Distance between distal ends of R and L greater cornua-taken from lateral edges	43.15 ± 5.2	39.1 ± 6.0	0.000
Height of greater cornua at articulation point with body, Right	7.75 ± 1.01	6.81 ± 1.07	0.000
Height of greater cornua at articulation point with body, Left	7.75 ± 1.08	6.56 ± 1.02	0.000
Width of greater cornua at articulation point with body, Right	4.5 ± 0.7	4.1 ± 0.7	0.001
Width of greater cornua at articulation point with body, Left	4.59 ± 1.0	4.14 ± 0.8	0.002
Greatest width of distal end of greater cornua, Left	3.29 ± 0.88	3.16 ± 0.57	0.309*
Greatest width of distal end of greater cornua, Right	3.39 ± 0.72	3.13 ± 0.61	0.026*
Greatest height of distal end of greater cornua, Right	4.54 ± 0.96	4.18 ± 0.84	0.021
Greatest height of distal end of greater cornua, Left	4.46 ± 0.95	4.10 ± 0.80	0.022*

* Not statistically significant

Table 4 displays a similar trend among disarticulated hyoids with statistically significant results for all measurements except the widths of the distal ends of the left and right greater cornua.

Table 4. Average measurements (mm) and p-values of disarticulated hyoids.

Measurement	**Males**	**Females**	***p*-Value**
Maximum length of body	24.17 ± 2.41	20.55 ± 1.87	0.000
Maximum height of body	12.46 ± 1.20	10.73 ± 1.08	0.000
Width of greater cornua at articulation point with body, Right	4.34 ± 0.79	3.77 ± 0.59	0.000
Width of greater cornua at articulation point with body, Left	4.33 ± 0.97	3.72 ± 0.61	0.000
Height of greater cornua at articulation point with body, Right	7.15 ± 0.96	5.93 ± 0.75	0.000
Height of greater cornua at articulation point with body, Left	7.15 ± 1.00	5.85 ± 0.80	0.000
Maximum length of greater cornua, Left	31.05 ± 3.14	27.78 ± 3.02	0.000
Maximum length of greater cornua, Right	31.58 ± 3.13	27.90 ±3.01	0.000
Greatest width of distal end of greater cornua, Left	3.07 ± 0.75	3.11 ± 0.50	0.694*
Greatest width of distal end of greater cornua, Right	3.19 ± 0.83	3.14 ± 0.54	0.595*
Greatest height of distal end of greater cornua, Left	4.47 ± 0.99	4.18 ± 0.73	0.029
Greatest height of distal end of greater cornua, Right	4.44 ± 0.98	4.19 ± 0.70	0.046

* Not statistically significant

Linear Regression Analyses Results

Linear regression analyses were used to test for differences in shape at the site of each measurement. As is displayed in Figure 4, which shows the results of the analysis performed on articulated hyoids, the majority of the female measurements resulted in negative residuals whereas the majority of male measurements resulted in positive residuals. This suggests that when males and females are reduced to the same size, females still are relatively smaller in several dimensions in relation to males, as indicated by the negative residual. Conversely, a positive residual indicates that the measurement is relatively larger than its negative counterpart. Alternatively, it may be possible that the regression on the geometric mean did not fully remove the effect of size.

After running *t*-tests, nine out of 15 measurements taken of articulated hyoids show statistically significant differences in shape. Table 5 lists the residuals of each measurement as well as its associated *p*-value. Figure 4 also displays a correlation between size and shape of the hyoid at two measurements. Measurements 12 and 15, the only two to show no statistically significant differences in size between males and females, display regression residuals that are opposite the rest of the residuals so that the male mean for both measurements was negative while the female was positive. These results suggest correlations between the distal end of the left greater cornua and differences in size and shape due to sex that deviate from the pattern of dimorphism found in the majority of the articulated hyoid measurements.

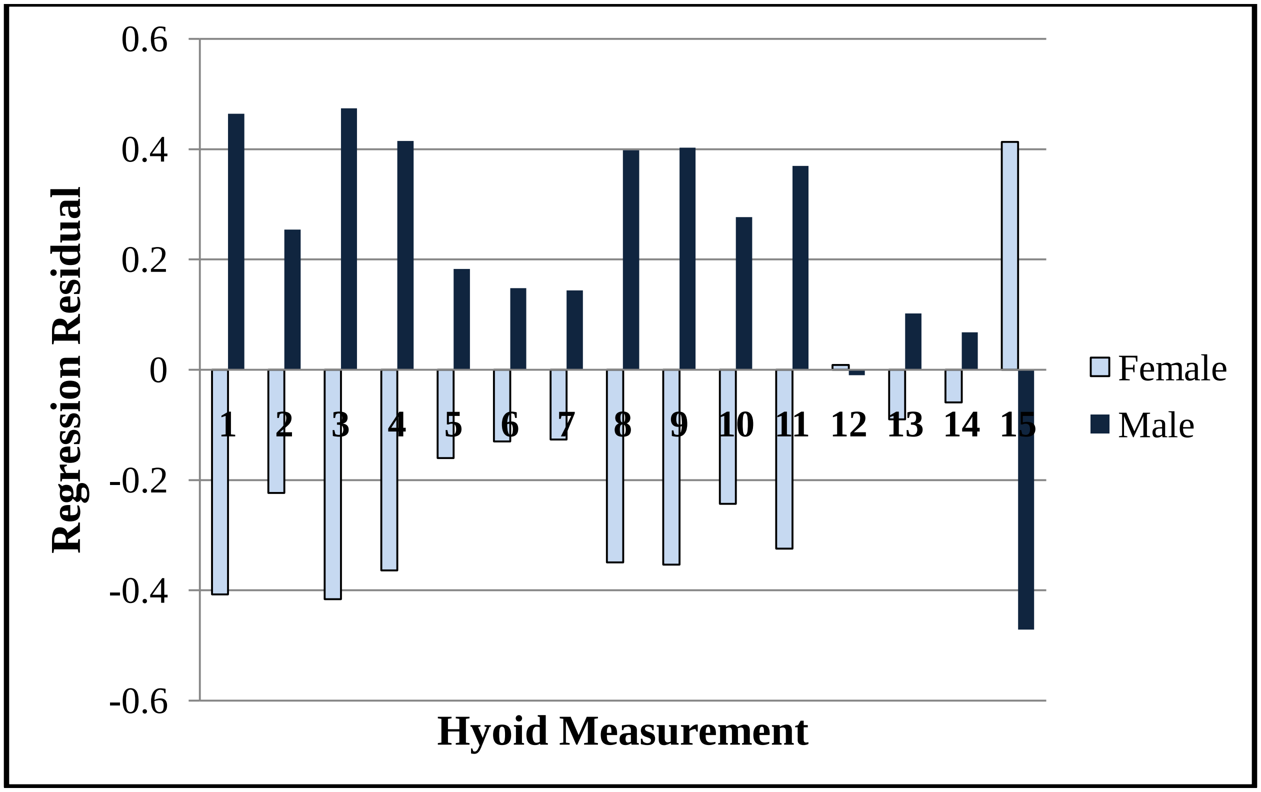

Figure 4. Regression residuals of each measurement for articulated hyoids indicating differences in shape between males and females.

Table 5. Regression residuals and p-values used to demonstrate differences in shape of articulated hyoids.

Measurement	Males	Females	*p*-Value
Total hyoid length	0.464	-0.407	0.000
Total hyoid width	0.254	-0.223	0.013
Maximum length of body	0.474	-0.416	0.000
Maximum height of body	0.415	-0.364	0.000
Maximum length of greater cornua, Right	0.183	-0.160	0.075*
Maximum length of greater cornua, Left	0.148	-0.130	0.151*
Distance between distal ends of R and L greater cornua-taken from lateral edges	0.144	-0.126	0.162*
Height of greater cornua at articulation point with body, Right	0.398	-0.349	0.000
Height of greater cornua at articulation point with body, Left	0.403	-0.353	0.000
Width of greater cornua at articulation point with body, Right	0.277	-0.243	0.006
Width of greater cornua at articulation point with body, Left	0.370	-0.324	0.000
Greatest width of distal end of greater cornua, Left	-0.010	0.009	0.922*
Greatest width of distal end of greater cornua, Right	0.102	-0.090	0.322*
Greatest height of distal end of greater cornua, Right	0.068	-0.059	0.513*
Greatest height of distal end of greater cornua, Left	-0.471	0.413	0.000

* Not statistically significant

A somewhat different trend is seen when the regression analysis is performed using disarticulated hyoids. In this case, the majority of the male residuals, eight of the 12 measurements, were negative whereas the same number of female residuals was positive. Figure 5 illustrates the differences between the residuals of male and female disarticulated hyoids.

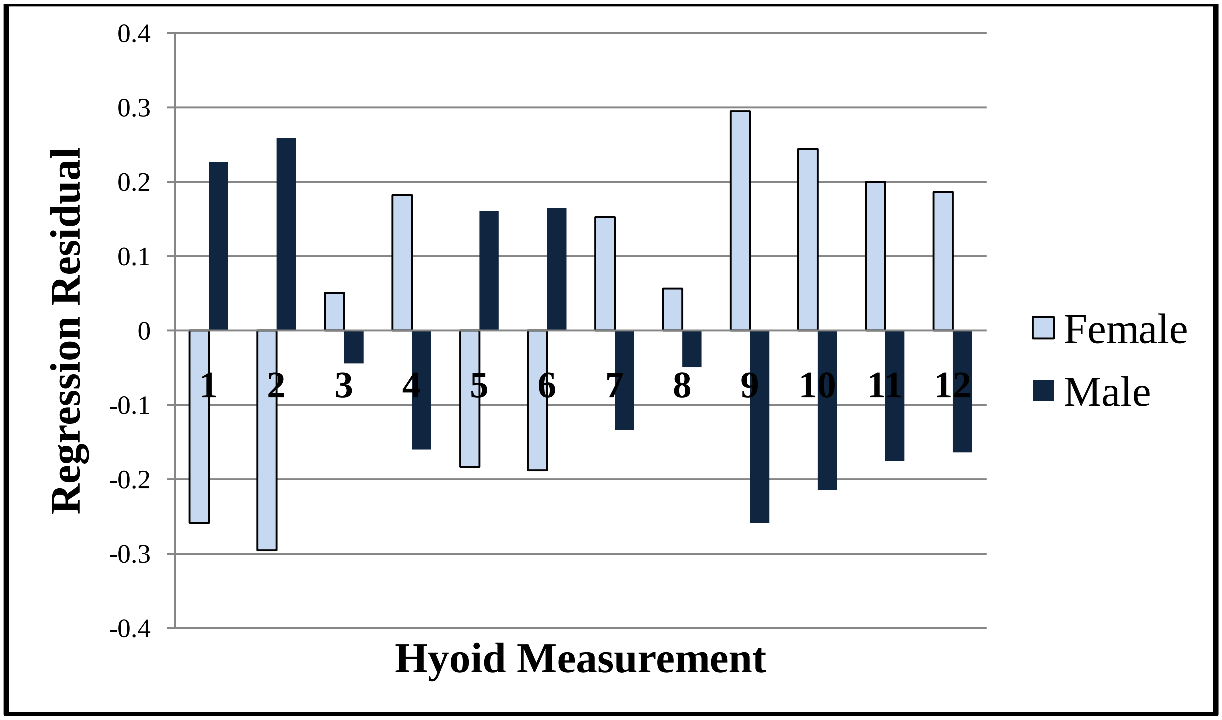

Figure 5. Regression residuals of each measurement for disarticulated hyoids indicating differences in shape between males and females.

t-tests were performed in order to determine whether the shape differences at each measurement site were statistically significant. Based on the resultant *p*-values, nine out of the 12 measurements were determined to exhibit significantly different shapes between males and females. Table 6 lists the residuals of each measurement for both males and females and their corresponding *p*-values.

Table 6. Regression residuals and p-values used to demonstrate differences in shape of disarticulated hyoids.

Measurement	**Males**	**Females**	***p*-Value**
Maximum length of body	0.227	-0.258	0.002
Maximum height of body	0.259	-0.295	0.001
Width of greater cornua at articulation point with body, Right	-0.044	0.051	0.560*
Width of greater cornua at articulation point with body, Left	-0.160	0.182	0.034
Height of greater cornua at articulation point with body, Right	0.161	-0.183	0.033
Height of greater cornua at articulation point with body, Left	0.165	-0.188	0.029
Maximum length of greater cornua, Left	-0.134	0.153	0.077*
Maximum length of greater cornua, Right	-0.049	0.056	0.515*
Greatest width of distal end of greater cornua, Left	-0.258	0.295	0.001
Greatest width of distal end of greater cornua, Right	-0.214	0.244	0.004
Greatest height of distal end of greater cornua, Right	-0.175	0.200	0.020
Greatest height of distal end of greater cornua, Left	-0.164	0.187	0.030

* Not statistically significant

Discriminant Function One – Articulated Hyoids

In using stepwise statistics, each step was statistically significant at p = 0.000. For articulated hyoids, three variables combine to result in the lowest Wilk's lambda. These variables are total length of the hyoid (Measurement 1), maximum length of the body (Measurement 3), and the height of the left greater cornua at its articulation point with the body (Measurement 9). The discrimination ability of the function is high with a canonical correlation of 0.702, an eigenvalue of 0.972, and Wilk's lambda of a canonical discriminant function was 0.000. These values indicate that the function is producing statistically significant discriminant function scores between the groups of males and females.

A discriminant function utilizing the three variables, their unstandardized discriminant coefficients, and the constant produces the discriminant score for each hyoid. See Table 7 for a summary of the unstandardized coefficients for each variable and the constant for articulated hyoids. The discriminant function will hereafter be referred to as Function 1 and is as follows:

$$\text{Discriminant score (D)} = (0.154)(X_1) + (0.228)(X_2) + (0.369)(X_3) - 13.129$$

If the resulting discriminant score is above the cutoff point of 0.0645, which is the mean of the average discriminant scores for both males and females, the individual is likely to be male while if the score is below the cutoff point the individual is likely to be female. In the classification results, a total of 83.1% of females and 88.7% of males were correctly classified while a total of 85.7% of total cases were classified correctly based on this function (Table 8). Figure 6 displays the distribution of discriminant scores for the 107 male and female articulated hyoids that were used to develop Function 1.

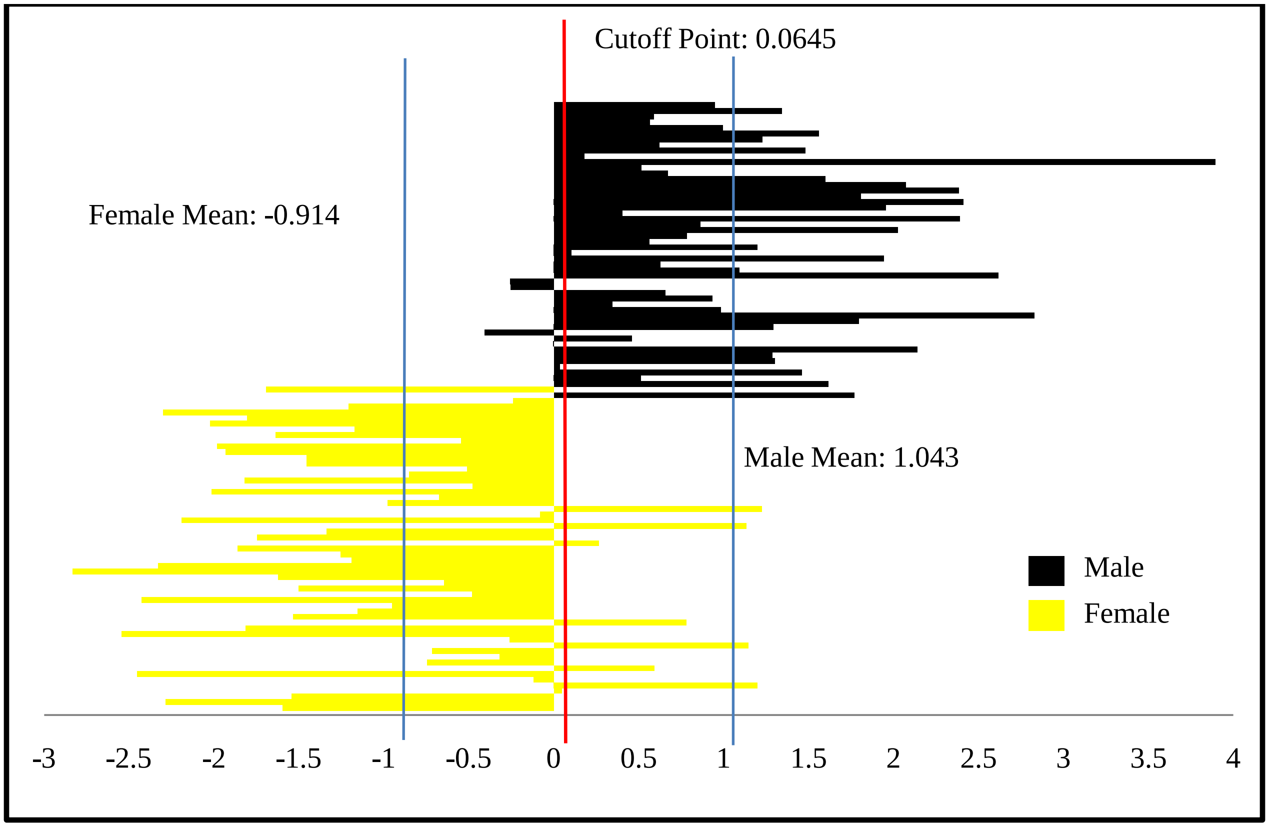

Figure 6. Distribution of discriminant scores for articulated males and females used to test Function 1.

Table 7. Unstandardized discriminant function coefficients of articulated hyoids used to develop Function 1.

Measurement	**Unstandardized Discriminant Function Coefficients**
1 (X_1)	0.154
3 (X_2)	0.228
9 (X_3)	0.369
Constant	-13.129

Table 8. Probabilities of group membership of articulated hyoids used to test Function 1.

		Sex	Predicted Group Membership .00	1.00	Total
Original	Count	.00	69	14	83
		1.00	8	63	71
	%	.00	83.1	16.9	100.0
		1.00	11.3	88.7	100.0

85.7% of original grouped cases correctly classified.

Discriminant Function Two – Disarticulated Hyoids

Once the stepwise statistical method had been applied to the sample population of disarticulated hyoids, five variables combined to offer the lowest Wilk's lambda value. These variables are maximum length of the body (Measurement 1), maximum height of the body (Measurement 2), width of the left greater cornua at its articulation point with the body (Measurement 4), height of the left greater cornua at its articulation point with the body (Measurement 6), and the maximum length of the right greater cornua (Measurement 8). The discrimination ability of the function is high with a canonical correlation of 0.780, an eigenvalue of 1.551, and Wilk's lambda of a canonical discriminant function was 0.000. These values indicate that the function is producing statistically significant discriminant function scores between the groups of males and females.

A discriminant function utilizing the five variables, their unstandardized discriminant coefficients, and the constant produces the discriminant score for each disarticulated hyoid. See Table 9 for a summary of the unstandardized coefficients for each variable and the constant for articulated hyoids.

The discriminant function will from now on be referred to as Function 2 and is as follows:

Discriminant score (D) = $(0.264)(X_1) + (0.372)(X_2) + (-0.431)(X_3) + (0.369)(X_4) + (0.113)(X_5) - 14.276$

If the resulting discriminant score is above the cutoff point of -0.0815, which is the mean of the average discriminant scores for both males and females, the individual is likely to be male while if the score is below the cutoff point the individual is likely to be female. In the classification results, a total of 88.9% of females and 87.4% of males were correctly classified based on this function while a total of 88.1% of total classes were correctly classified (Table 10). Figure 7 displays the distribution of discriminant scores for the 152 disarticulated hyoids that were used to develop Function 2.

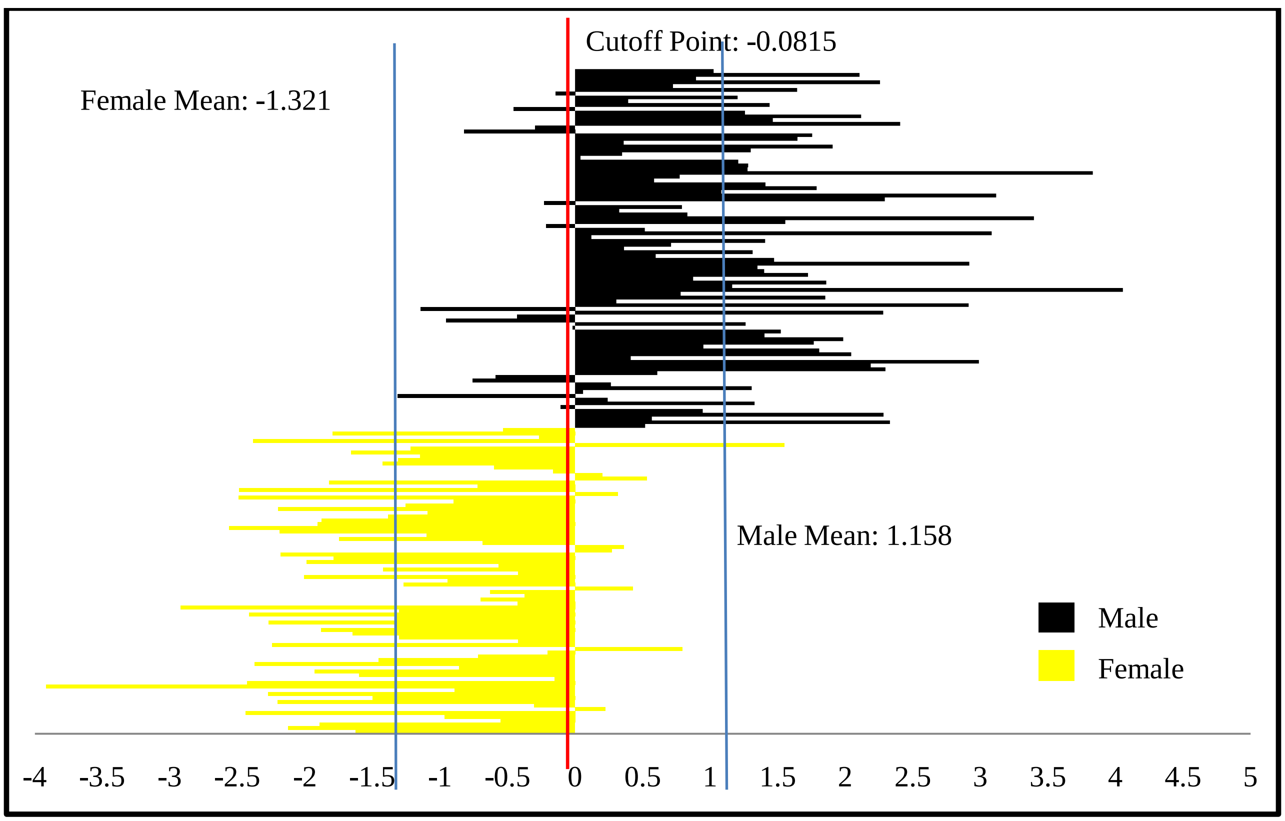

Figure 7. Distribution of discriminant scores for disarticulated males and females used to test Function 2.

Table 9. Unstandardized discriminant function coefficients of disarticulated hyoids used to develop Function 2.

Measurement	**Unstandardized Discriminant Function Coefficients**
1 (X_1)	0.264
2 (X_2)	0.372
4 (X_3)	-0.431
6 (X_4)	0.369
8 (X_5)	0.113
Constant	-14.276

Table 10. Probabilities of group membership of disarticulated hyoids used to test Function 2.

			Predicted Group Membership		
		Sex	.00	1.00	Total
Original	Count	.00	72	9	81
		1.00	12	83	95
	%	.00	88.9	11.1	100.0
		1.00	12.6	87.4	100.0

88.1% of original grouped cases correctly classified.

Discriminant Function Three – All Measurements of Articulated and Disarticulated Hyoids

The previous discriminant function analyses were performed using separate populations of articulated and disarticulated hyoids so as to develop two different equations that could be used based on the condition of the hyoid being used. This way, if a completely disarticulated hyoid, or a unilaterally ossified hyoid, is recovered there is a separate discriminant function based on measurements of disarticulated hyoids that may work better than a function based on articulated hyoid measurements. The same is true for a recovered articulated hyoid. However, in order to take advantage of the complete sample, two analyses were performed using both groups. The first included all measurements of articulated and disarticulated hyoids while the second used only those measurements that the two groups had in common. This will allow the function developed using all measurements to be used when dealing with an articulated hyoid while the function developed using only those measurements that the two groups had in common to be used on disarticulated hyoids.

Unfortunately, because the measurement that is most influential when dealing with articulated hyoids, the total length of the bone, is not present when dealing with a disarticulated hyoid, the sample of disarticulated hyoids could not be used in conjunction with the sample of articulated hyoids to create a separate discriminant function. This measurement was removed in order to test the applicability of a function created without it and three measurements were found to combine to produce the smallest Wilks' lambda. These are the maximum length of the body (Measurement 3 of articulated and 1 of disarticulated hyoids), the maximum length of the right greater cornua (Measurement 11 of articulated and 8 of disarticulated hyoids), and the maximum height of the body (Measurement 4 of articulated and 2 of disarticulated hyoids). The discrimination ability of this function is the lowest of those functions developed so far with a canonical correlation of 0.679 and an eigenvalue of 0.854. The Wilks' lambda of a canonical discriminant function is still 0.000, indicating that the function is producing statistically significant discriminant function scores between the groups of males and females. However, this function is unique in that it was developed using only the articulated sample but its classification ability was tested using the entire sample of articulated and disarticulated hyoids.

A discriminant function utilizing the three variables, their unstandardized discriminant coefficients, and the constant produces the discriminant score for each hyoid. See Table 11 for a summary of the unstandardized coefficients for each variable and the constant for articulated hyoids.

The discriminant function will be referred to as Function 3 from now on and is as follows:

$$\text{Discriminant score (D)} = (0.215)(X_1) + (0.374)(X_2) + (0.153)(X_3) - 13.473$$

If the resulting discriminant score is above the cutoff point of 0.06, which is the mean of the average discriminant scores for both males and females, the individual is likely to be male while if the score is below the cutoff point the individual is likely to be female. In the classification results, a total of 81% of females and 85.9% of males were correctly classified based on this function while 83.1% of total cases were correctly classified (Table 12). This function produces the lowest percentage of correctly classified hyoids due to the removal of the most influential measurement. Figure 8 displays the discriminant scores for the sample population used to develop Function 3.

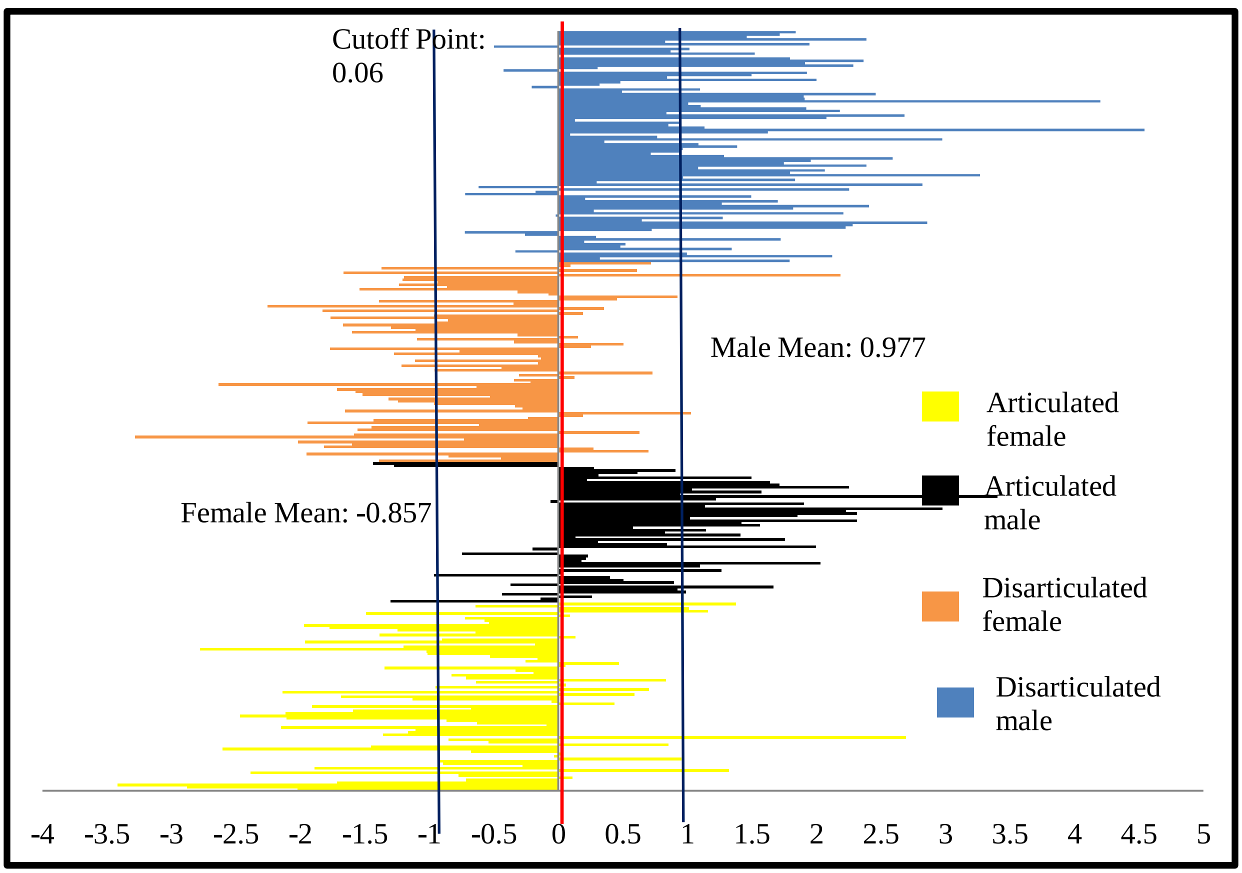

Figure 8. Distribution of discriminant scores for both articulated and disarticulated males and females used to test Function 3.

Table 11. Unstandardized discriminant function coefficients of articulated and disarticulated hyoids used to develop Function 3.

Measurement	**Unstandardized Discriminant Function Coefficients**
3; 1 (X_1)	0.215
4; 2 (X_2)	0.374
5; 8 (X_3)	0.153
Constant	-13.473

Table 12. Probabilities of group membership of articulated and disarticulated hyoids used to test Function 3.

			Predicted Group Membership		
		Sex	.00	1.00	Total
Original	Count	.00	132	31	163
		1.00	22	134	156
	%	.00	81.0	19.0	100.0
		1.00	14.1	85.9	100.0

a. 83.4% of original grouped cases correctly classified.

Discriminant Function Four – Measurements Shared Between Articulated and Disarticulated Hyoids

A fourth discriminant function was developed using only those 12 measurements that both the articulated and disarticulated hyoids had in common. Stepwise statistics produced five measurements that combined to produce the lowest Wilks' lambda. These measurements are the maximum length of the body (Measurement 3 of articulated and 1 of disarticulated hyoids), maximum height of the body (Measurement 4 of articulated and 2 of disarticulated hyoids), maximum length of the right greater cornua (Measurement 11 of articulated and 8 of disarticulated hyoids), height of the left greater cornua at articulation point with the body (Measurement 9 of articulated and 6 of disarticulated hyoids), and the width of the left greater cornua at articulation point with the body (Measurement 7 of articulated and 4 of disarticulated hyoids).

The discrimination ability of this function is high with a canonical correlation of 0.750 and an eigenvalue of 1.288. The Wilks' lambda of a canonical discriminant function is still 0.000, indicating that the function is producing statistically significant discriminant function scores between the groups of males and females.

A discriminant function utilizing the five variables, their unstandardized discriminant coefficients, and the constant produces the discriminant score for each hyoid. See Table 13 for a summary of the unstandardized coefficients for each variable and the constant for articulated hyoids. The discriminant function will from now on be referred to as Function 4 and is as follows:

$$\text{Discriminant score (D)} = (0.242)(X_1) + (0.347)(X_2) + (-0.445)(X_3) + (0.395)(X_4) + (0.125)(X_5) - 13.881$$

If the resulting discriminant score is above the cutoff point of -0.0135, which is the mean of the average discriminant scores for both males and females, the individual is likely to be male while if the score is below the cutoff point the individual is likely to be female. In the classification results, a total of 85.5% of females and 85% of males and 86.3% of total cases were correctly classified based on this function (Table 14). Figure 9 shows the discriminant scores for the sample population used to develop Function 4.

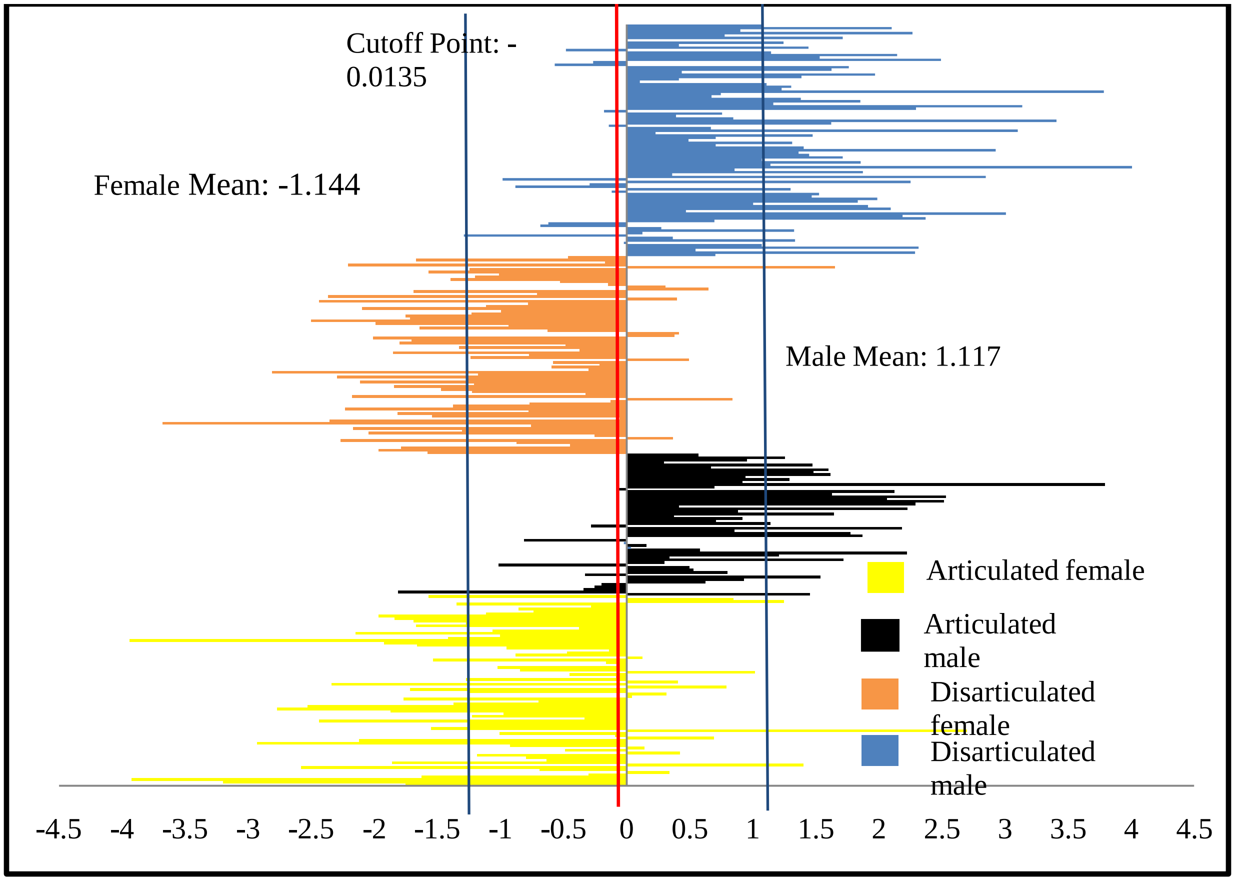

Figure 9. Distribution of discriminant scores for both articulated and disarticulated males and females used to test Function 4.

Table 13. Unstandardized discriminant function coefficients of articulated and disarticulated hyoids used to develop Function 4.

Measurement	**Unstandardized Discriminant Function Coefficients**
3; 1 (X_1)	0.242
4; 2 (X_2)	0.347
5; 8 (X_3)	-0.445
9; 6 (X_4)	0.396
11; 4 (X_5)	0.125
Constant	-13.881

Table 14. Probabilities of group membership of articulated and disarticulated hyoids used to test Function 4.

			Predicted Group Membership		
		Sex	.00	1.00	Total
Original	Count	.00	136	23	159
		1.00	23	130	153
	%	.00	85.5	14.5	100.0
		1.00	15.0	85.0	100.0

a. 85.3% of original grouped cases correctly classified.

Discriminant Function Five – Body Measurements of Disarticulated Hyoids Only

Because the chances are good that a recovered hyoid will be disarticulated, it is most likely that the hyoid body will be the recovered portion, due to it being composed of denser bone than the greater cornua, and in the best condition to use in a discriminant function. Therefore a fifth function was developed using only the two measurements taken of the body of disarticulated hyoids in an attempt to test the usefulness of just the body in determining sex. Once the stepwise statistical method had been applied to the sample population of disarticulated hyoids, the discrimination ability of the function is high with a canonical correlation of 0.704, an eigenvalue of 0.985, and Wilk's lambda of a canonical discriminant function was 0.000. These values indicate that the function is producing statistically significant discriminant function scores between the groups of males and females.

A discriminant function utilizing the two variables, their unstandardized discriminant coefficients, and the constant produces the discriminant score for each disarticulated hyoid. See

Table 15 for a summary of the unstandardized coefficients for each variable and the constant for those disarticulated hyoids.

The discriminant function will from now on be referred to as Function 5 and is as follows:

$$\text{Discriminant score (D)} = (0.313)(X_1) + (0.495)(X_2) - 12.827$$

If the resulting discriminant score is above the cutoff point of -0.092, which is the mean of the average discriminant scores for both males and females, the individual is likely to be male while if the score is below the cutoff point the individual is likely to be female. In the classification results, a total of 85.4% of females and 80.6% of males were correctly classified based on this function while a total of 82.8% of total classes were correctly classified (Table 16). Figure 10 displays the distribution of discriminant scores for the 227disarticulated hyoids that were used to develop Function 5.

Table 15. Unstandardized discriminant function coefficients of disarticulated hyoids used to develop Function 5.

Measurement	**Unstandardized Discriminant Function Coefficients**
1 (X_1)	0.313
2 (X_2)	0.495
Constant	-12.827

Table 16. Probabilities of group membership of disarticulated hyoids used to test Function 5.

			Predicted Group Membership		
		Sex	.00	1.00	Total
Original	Count	.00	88	15	103
		1.00	24	100	124
	%	.00	85.4	14.6	100.0
		1.00	19.4	80.6	100.0

a. 82.8% of original grouped cases correctly classified.

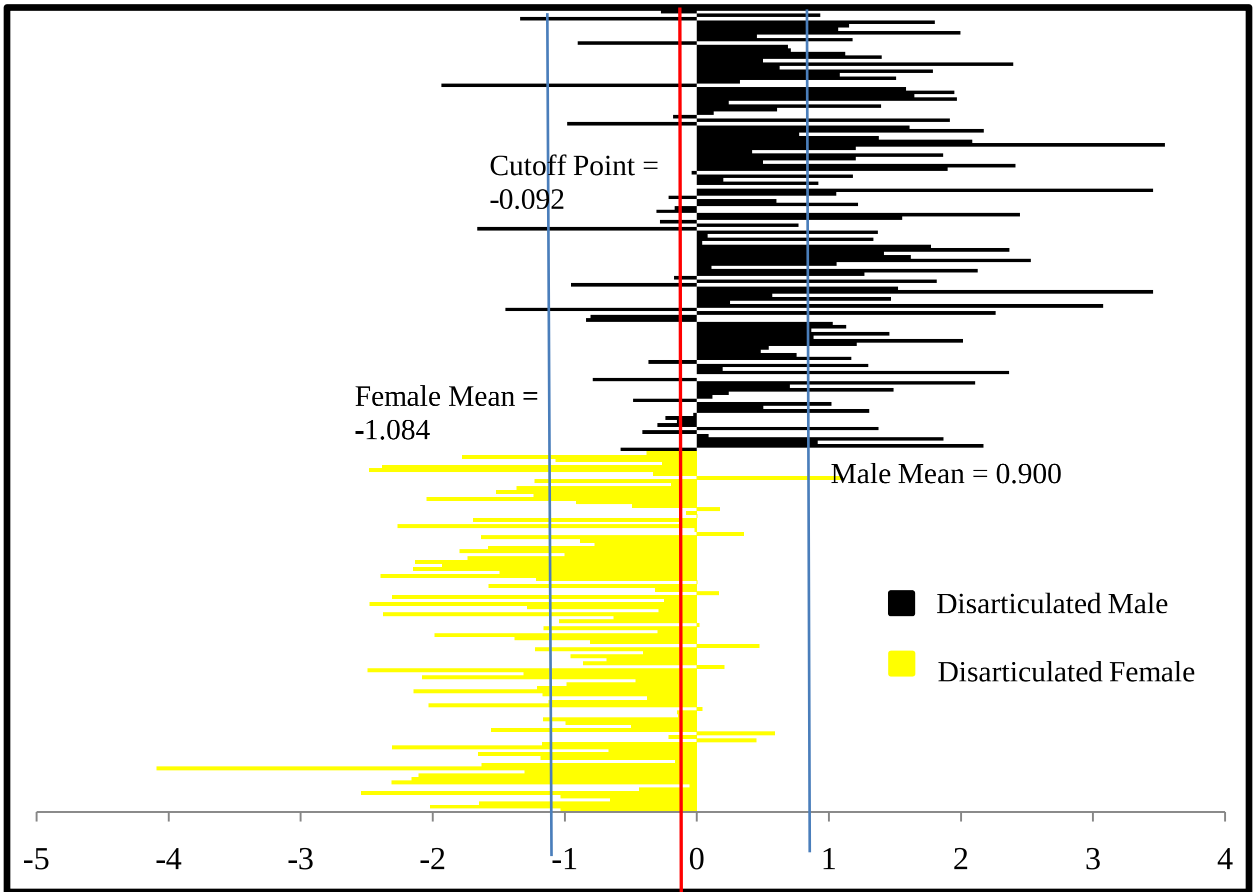

Figure 10. Distribution of discriminant scores for the disarticulated hyoids used to test Function 5.

Unfortunately, because of the differential preservation of the hyoids in the Terry Collection not all of the measurements could actually be taken from each bone. This led to the exclusion of some hyoids in the discriminant function analysis process so that not all of the 169 articulated and 229 disarticulated hyoids were used because they were missing a measurement that was a part of the equation. Table 17 lists the sample size used in each analysis and the resulting discriminant function. It is important to note that the classification statistics for Functions 1, 2, and 5 were results of testing the functions on just the isolated articulated and disarticulated samples while Functions 3 and 4 were tested using the entire sample population of 398 hyoids.

Table 17. Summary of the sample populations used to test each discriminant function and its overall accuracy.

Discriminant Function	**Sample**	**Accuracy of Function**
Function 1	107 articulated: 57 female; 50 male	85.7%
Function 2	152 disarticulated: 71 female; 81 male	88.1%
Function 3	259 articulated and disarticulated: 128 female; 131 male	83.4%
Function 4	259 articulated and disarticulated; 128 female; 131 male	85.3%
Function 5	227 disarticulated: 103 female; 124 male	82.8%

Discussion

Using the Discriminant Functions

The purpose of developing five different discriminant functions is to provide multiple opportunities for the physical anthropologist to classify a hyoid as either male or female regardless of whether the greater cornua are fused to the body. Therefore these functions are best used in conjunction with each other so that a determination of sex is not based on one single function. If a fully articulated hyoid is recovered the best function to use would be Function 1 because it was developed based on a sample population composed solely of articulated hyoids. However, Functions 2, 3, 4, and 5 should also be used because they utilize measurements that both disarticulated and articulated hyoids have in common. The same is true of a recovered disarticulated hyoid. The best function to use would be Function 2 which was developed using only a sample of disarticulated hyoids, but Functions 3, 4, and 5 should also be used because they are based on measurements that articulated and disarticulated hyoids have in common and just the hyoid body. If only the body is recovered the best function to use would be Function 5 because it was developed specifically to be used to determine sex of a body. Using multiple functions will allow for better accuracy when determining whether a hyoid is male or female. Tables 18, 19, 20, 21, and 22 compile the measurements needed and discriminant score for each function.

It is also important to note that although the left and right measurements were used separately to develop the discriminant functions, they can be interchangeable if the necessary element is not present. So, for example, if a hyoid body and right greater cornua are recovered, Functions 2, 3, 4, and 5 can all still be utilized by substituting the measurements which are supposed to be taken of the left greater cornua with measurements taken of the right greater cornua. This interchangeability was determined by testing the accuracy of discriminant function analysis using the right and left measurements separately. The analyses were extremely close in accuracy, for both articulated and disarticulated hyoids, suggesting the left or right measurements can be substituted for the one that is missing.

Table 18. A compilation of the information needed to use Function 1.

Discriminant score (D) = (0.154)(X_1) + (0.228)(X_2) + (0.369)(X_3) – 13.129	
Measurement	Total hyoid length (X_1) Maximum length of body (X_2) Height of left greater cornua at articulation point with body (X_3)
Cutoff Point	0.0645 Above: Likely male Below: Likely female

Table 19. A compilation of the information needed to use Function 2.

Discriminant score (D) = (0.264)(X_1) + (0.372)(X_2) + (-0.431)(X_3) + (0.369)(X_4) + (0.113)(X_5) – 14.276	
Measurement	Maximum length of body(X_1) Maximum height of body (X_2) Width of left greater cornua at articulation point with body(X_3) Height of left greater cornua at articulation point with body (X_4) Maximum length of right greater cornua (X_5)
Cutoff Point	-0.0815 Above: Likely male Below: Likely female

Table 20. A compilation of the information needed to use Function 3.

Discriminant score (D) = (0.215)(X_1) + (0.374)(X_2) + (0.153)(X_3) – 13.473	
Measurement	Maximum length of the body (X_1) Maximum length of the right greater cornua (X_2) Maximum height of the body (X_3)
Cutoff Point	0.06 Above: Likely male Below: Likely female

Table 21. A compilation of the information needed to uses Function 4.

Discriminant score (D) = (0.242)(X_1) + (0.347)(X_2) + (-0.445)(X_3) + (0.395)(X_4) + (0.125)(X_5) – 13.881	
Measurement	Maximum length of the body (X_1) Maximum height of the body (X_2) Maximum length of the right greater cornua (X_3) Height of the left greater cornua at articulation point with the body (X_4) Width of the left greater cornua at articulation point with the body (X_5)
Cutoff Point	-0.0135 Above: Likely male Below: Likely female

Table 22. A compilation of information needed to use Function 5.

Discriminant score (D) = (0.313)(X_1) + (0.495)(X_2) – 12.827	
Measurement	Maximum length of the body (X_1) Maximum height of the body(X_2)
Cutoff Point	-0.092 Above: Likely male Below: Likely female

Accuracy Comparison of Sexing Methods

One advantage of this research in contrast to those previously published is that this study utilizes both articulated and disarticulated hyoids, including those that are unilaterally articulated meaning one greater horn is fused to the body. Because previous studies of hyoid size and shape have utilized only fully articulated hyoids, either from a skeletal collection (Pollanen and Ubelaker, 1997; Lekšan et al., 2005) or from cadavers (Papadopoulos et al, 1989; Miller et al., 1998; Reesink et al., 1999; Kim et al., 2006), the applicability of discriminant function analysis using disarticulated hyoids had not yet been tested. Although the hyoid from an autopsied individual or a medical school cadaver may be disarticulated once the tissue has been removed, these studies purposely left enough tissue to keep the bone's shape, simulating complete articulation. However, if a hyoid is found in an archaeological or forensic setting, unless the greater cornua are actually ossified to the body, the likelihood of finding an articulated hyoid is significantly decreased as the tissues holding the bone together will have likely decomposed. In fact, of the 398 hyoids used in this study 229 were disarticulated with 87 of them exhibiting unilateral fusion. Based on these numbers the likelihood that a disarticulated hyoid will be recovered is greater than 50%, demonstrating the need for methods of sexing disarticulated as well as articulated hyoids.

When discriminant function analysis was applied to the population of disarticulated hyoids it was unclear how accurately they would be classified because those measurements that were expected to be most sexually dimorphic, total length and width, could not be taken. However, Function 2, which was developed based only on disarticulated hyoids, actually classifies disarticulated hyoids at a higher rate of accuracy than Function 1 classifies articulated ones. This is likely due to the use of five rather than three measurements in the discriminant function, allowing the function to better analyze the overall size of the bone. With an accuracy rate of 88% this function is the most accurate of the five developed. In addition, Function 5 utilizes only two measurements on the hyoid body and correctly classified almost 83% of hyoids. These two functions suggest that disarticulated hyoids, even if only the body is present, can be used to correctly sex an individual.

Three previous studies used discriminant function analysis with varying degrees of success to develop a function that could be used to classify a hyoid as male or female. Reesink et al. (1999) used three dimensions of the body to develop an equation that classified their sample with an overall accuracy of 76%. While this study suggests the hyoid body is a very sexually dimorphic portion of the bone, the function was developed and tested using only 39 individuals which may explain why its accuracy is only 76%. Miller and colleagues (1998) found similar results with a function that they developed using five measurements. Their function, based on a sample of 315 individuals, classified 69.2% of males and 75.2% of females correctly. In contrast, Kim et al. (2006) took measurements of only 85 hyoids to produce an equation using three measurements that resulted in an overall accuracy of 88.2%.

While sample size may have some influence on the differences in accuracy of each function, it is also likely that the method of measurement has had some effect on the accuracy. Studies performed by Miller et al. (1998) and Reesink et al. (1999) both first radiographed each hyoid and took measurements from the images whereas Kim and colleagues (2006) took a digital photograph of each bone and took measurements from the photograph. Taking measurements from a radiograph can be problematic due to dimensional distortion resulting from the angle at which it was taken, the presence of soft tissue, and the bone density of each hyoid (Lekšan et al., 2005). Because these studies were performed using a cadaveric sample population in which tissue was removed from the bone before it was X-rayed, there is a possibility that a small amount of remaining tissue altered the measurement taken from the radiograph. Similarly, differences in bone density may alter the measurement if there are some portions of the bone that do not show up on the radiograph. Therefore the most accurate methods are likely those used in this study, taking measurements directly from the bone, and the use of digital photographs rather than radiographs, used by Kim and colleagues (2006).

The best methods for determining sex are those using morphological as well as metric traits of the skull and pelvis. Perhaps the most well known and preferred method is that of the Phenice technique using three morphological traits to sex the os coxae. Although Phenice reported an accuracy rate of approximately 96% (1969), later studies reported less accurate findings, likely due to the relative inexperience of the users. A study performed by Lovell (1989) in which 12 participants attempted to sex 50 pubic bones using the Phenice technique, resulted in an overall accuracy rate of about 83%. Ubelaker and Volk (2002) performed a similar study by testing the use of the method by an individual knowledgeable of each of the three traits but with no further knowledge of traits of the pelvis indicative of sex. Sex was correctly determined for 88.4% of the sample, indicating this method is not as accurate when used by someone with limited experience. When compared to the Phenice technique, the discriminant functions presented in this study have the ability to classify the hyoid at relatively similar rates, indicating that it has the ability to be used to determine sex.

One of the most common tools used to metrically determine sex of an individual is the use of FORDISC, a computer program that uses discriminant function analysis and regression analysis to provide a rough biological profile of skeletal material based on a series of measurements. The functions utilized by FORDISC were developed using a skeletal population composed of the American Forensic Data Bank and the Terry and Hamann Todd Collections (Ramsthaler et al., 2007). A study was recently published testing the accuracy of FORDISC in correctly predicting the sex of 98 skulls and found that the average accuracy of FORDISC was 86% (Ramsthaler et al., 2007). Once again the accuracy rates of the discriminant functions presented in this study are comparable to an established method of determining sex, indicating they are applicable when attempting to determine sex of skeletal remains where the hyoid is present. Refer to Table 23 for a summary of the sexing methods and accuracies previously discussed.

Table 23. Summary of commonly used sexing methods and their accuracies as compared to the discriminant functions presented in this chapter.

Author	Skeletal Element Used	Method	Accuracy	Sample Used
Present study, 2009	Hyoid	Discriminant function analysis	83-88%	398 individuals from the Terry Collection
Kim et al., 2006	Hyoid	Discriminant function analysis	88.2%	85 cadavers
Miller et al., 1998	Hyoid	Discriminant function analysis	69.2% (males); 75.2% (females)	315 cadavers
Reesink et al., 1999	Hyoid	Discriminant function analysis	76%	59 cadavers
Phenice, 1969	Pelvis	Morphological analysis	96%	275 individuals from the Terry Collection
Lovell, 1989	Pelvis	Morphological analysis-Phenice technique	83%	50 cadavers
Ubelaker and Volk, 2000	Pelvis	Morphological analysis-Phenice technique	88.4%	198 individuals from the Terry Collection
Ramsthaler et al., 2007	Skull	FORDISC	86%	98 individuals from cranium collections

Hyoid Shape

Because metric analyses of hyoids are typically focused on size rather than morphological shape, it is possible that misclassifications can occur for those bones that are closer in size to members of the opposite sex rather than those of its own sex. This may result in smaller males being erroneously classified as females and larger females classified as males. However, by removing size from the sex determination process the likelihood of misclassifications could be decreased. Unfortunately, specific shapes are often difficult to judge and observer bias may be introduced when trying to classify the hyoid as one particular shape or the other. Using a purely metric, statistical method provides an objective approach to testing for differences in shape.

The shape of the hyoid has been a subject of discussion (see Papadopoulos et al., 1989; Pollanen and Ubelaker, 1997; Miller et al., 1998; Lekšan et al., 2005) but while some agreement has been made regarding overall shapes, there have been differing results when comparing shape and sex. Because assigning a shape to the bone is somewhat of a subjective process, a number of different shapes have been established, some of which have been used by multiple researchers while others have not. In addition, some studies have found links between hyoid shape and sex (Papadopoulos et al, 1989; Lekšan et al., 2005; Koebke and Saternus, 1979) while others have not (Pollanen and Ubelaker, 1997).

The hyoid is commonly described as being horseshoe in shape (Shimizu et al., 2005; Papadopoulos et al., 1989) but a number of classifications have been made within this general category. Most common is the distinction of symmetrical and asymmetrical shapes with the symmetrical hyoids being broken into parabolic and hyperbolic. Typically hyperbolic is defined as having similar dimensions of breadth and length whereas parabolic hyoids tend to have greater breadths than lengths (Miller et al., 1998; Pollanen and Ubelaker, 1997). This leads to hyperbolic hyoids being U-shaped while parabolic hyoids are V-shaped, hence the common use of the terms U-type and V-type to describe the shape of the bone (Papadopoulos et al., 1989; Lekšan et al., 2005; Pollanen and Ubelaker, 1997). Asymmetrical hyoids are those that have disproportionate lengths of greater cornua (Lekšan et al., 2005), leading to an overall asymmetrical shape when the bone is divided down the sagittal plane.

Papadopoulos and colleagues (1989) took the classification process one step further and divided the hyoids used in their study into five different shapes known as Types U, H, B, D, and V. Types B and V are essentially variations of the parabolic shape, Type U can also be known as hyperbolic, Type D is asymmetrical, and Type H is described as being horseshoe. Further subdivisions of these five classifications can be made based on symmetry, isometry, width of the bone, and its two-dimensional size. This is an extreme case of shape discrimination and these categories have generally not been used in later research.

Studies looking at links between hyoid shape and sex have seen differing results. After performing both qualitative and quantitative analyses, Pollanen and Ubelaker (1997) found that although certain metric trends could be related to shape and sexual dimorphism, they found no significant correlation between shape and sex. The trends that they identified are a smaller overall size in females, similar length and breadth dimensions in hyperbolic hyoids, and greater breadths than lengths in parabolic hyoids. Each of these trends is to be expected based on previous research regarding relationships between dimensions and shape. However, this study is unique in that the authors did not find a relationship between sex and hyoid shape, suggesting either the sample size of 100 was too small or, more likely, more than two dimensions of the hyoid need to be analyzed in order to classify a hyoid as male or female based on its shape.

Other studies have had more success in correlating hyoid shape and sex. Lekšan and colleagues (2005) and Koebke and Saternus (1979) both found that the U-shaped hyperbolic hyoid is most common in females whereas the V-shaped parabolic hyoid is more common in males. In contrast to these findings Papadopoulos and colleagues (1989) found that hyperbolic and parabolic hyoids made up only 40% of their sample and were therefore not as highly represented when associated with sex. They found that Type D, or asymmetrical, hyoids are most common in males while Types H and B, or horseshoe and parabolic respectively, were equally common in females. However, these findings may contrast with Lekšan and colleagues (2005) and Koebke and Saternus

(1979) due to the authors' willingness to classify their sample into five, sometimes more, different shapes. Unfortunately the differing findings are indicative of the subjectivity involved in determining shape of a hyoid. This subjectivity may eventually lead to the misclassification of the bone so that, for example, a female hyoid may be classified as hyperbolic by one individual and parabolic by another. Depending on which shape is chosen, the correlation between sex and shape may increase or decrease in frequency and accuracy. This is why an unbiased method of distinguishing between shape and sex may be an extremely useful tool.

Lekšan and colleagues (2005) examined a metric rather than visual method of determining hyoid shape and then correlated the shape with sex. The two variables that they used to classify the shape are the proportion of right to left greater horn length and the angle between greater horns. The angle between greater horns was the most influential in determining the shape of the hyoid so that if the angle was less than 25° the bone is classified as the symmetrical U-type whereas an angle of greater than 25° is classified as symmetrical V-type (Lekšan et al., 2005). When comparing the shape to prevalence in sex, it was found that within females the symmetric U-type was more common while in males the symmetric V-type was more common.

Because many of the shape differences between males and females are related to sexual dimorphism of the bone (Pollanen and Ubelaker, 1997; Miller et al., 1998; Lekšan et al., 2005), using metric analysis to study differences in shape should be fairly simple as long as size has been removed. This study used linear regression analysis to analyze differences in shape of the male and female hyoid at the point of each measurement and found strong correlations between points that have been established as sexually dimorphic and statistically significant differences in shape. The analysis produced a series of residuals for each measurement with those below zero indicating the bone is relatively smaller in shape when compared to a positive residual for the same measurement. Those measurements which displayed statistically significant differences between residuals of males and females were focused upon in an attempt to determine patterns of shape differences between sexes.

It has been established that the female hyoid is overall smaller than the male and as a result the dimensions of female hyoids are smaller than male, possibly affecting the shape. For example, because the greater horns of a female are shorter in length than those of a male, the female hyoid tends to be shorter in an anterio-posterior direction (Lekšan et al., 2005). Therefore you would expect to see differences in the measurement of total hyoid length (Measurement 1). This study has shown statistically significant differences in size as well as shape of this measurement with the negative residual for the females indicating that when males and females are scaled to the same size, the female tends to be shorter in overall length. However, because most female residual means were negative, while male residual means were positive, this may suggest that the regression on hyoid measurements on the geometric mean failed to eliminate all of the “size” signal.

However, although the size differences between male and female hyoids were statistically significant for the lengths of both right and left greater cornua, the differences in shape were not enough to be significant. This suggests that, when the same size, the female greater cornua are relatively the same length as males and therefore are not the contributing factor to the overall length differences between males and females. It may be possible that the element which determines the overall longer shape in males may be the hyoid body which could exhibit more posterior curvature in males than females, therefore causing the overall length of male hyoids to be greater in not only size but also shape than in females.

In addition, it has been shown that female hyoids tend to be narrower due to smaller body length and distance between greater cornua (Lekšan et al., 2005). This trend is also demonstrated in this study with the shape differences between male and female body length and overall width being statistically significant. For both these variables the regression analysis produced negative residuals for females and positive residuals for males, suggesting the female hyoid body is relatively narrower than males and the overall width of the bone is narrower in females than males. However, the distance between the distal ends of the greater cornua, while statistically significant in size but not in shape, suggests that the overall shape of the greater cornua may differ between males and females so that the female is likely more straight with slight medial curvature toward the distal end while the male greater cornua may exhibit more lateral bowing of the greater cornua and more medial curvature of the distal ends. This would result in the male having an overall greater width but the distance between the distal ends of the greater cornua would be relatively similar to females, resulting in a difference in overall shape but not in the distance between the distal ends of the greater cornua.

It is important to note that the previous research described above, as well as the results described from this study, was performed on fully articulated hyoids, meaning both greater cornua were attached to the body. Those studies utilizing hyoids from a skeletal collection (Pollanen and Ubelaker, 1997; Lekšan et al., 2005) used only hyoids that displayed fusion between the greater horns and the body. Other studies removed all tissue from the bone except the tissue holding the greater cornua in place to the body (Papadopoulos et al., 1989; Miller et al., 1998). However, this study found relationships between shape and sex of disarticulated hyoids that were not expected based on those found of articulated hyoids.

It is not possible to assign a disarticulated hyoid a particular shape, but similar relationships between size, shape, and sex that are present in articulated hyoids were expected. Obviously several measurements that were taken from articulated hyoids could not be duplicated on disarticulated hyoids, such as total length, width, and distance between the lateral edges of the distal end of the greater cornua. However, just as female articulated hyoids are expected to be shorter and narrower, female disarticulated hyoids were expected to follow the same trend due to a shared decrease in size when compared to males. The length of the body follows this trend with statistically significant differences in both size and shape but the length of the greater cornua follows the same pattern as those of articulated hyoids. Although the differences between males and females are significant in size they are not significant in shape. This may indicate that the hyoid body rather than the greater cornua is one of the most important determining factors in the overall size and shape of the bone.

When the regression analysis was performed, 8 out of 12 residuals of males were negative while the same number of female residuals were positive. These results are very different from those of the articulated hyoids in which the majority of female residuals were negative and male residuals were positive, as was expected. The maximum length of the body follows the same trend seen with the articulated hyoid with the female body being relatively shorter when compared to the male, suggesting that when the hyoid is within the body it would have a narrower shape than disarticulated male hyoids. However, there was no way to test this hypothesis within this study. The greater cornua displayed results that were the opposite of articulated hyoids. Regression residuals produced after testing the length of the right and left greater cornua were negative for males and positive for females, indicating male greater cornua are relatively shorter than females, although the difference between the residuals was not statistically significant. Because male greater cornua are significantly longer than females when looking at size, the variation in shape could be due to the amount of curvature of the greater cornua with males exhibiting a similar pattern as that proposed with the articulated hyoids.

Conclusion

When constructing a biological profile of skeletal remains, it is imperative that the physical anthropologist use as many methods as possible for the elements that are present. This study, based on the well documented and thoroughly researched Robert J. Terry Collection, has demonstrated the usefulness of using the hyoid as a skeletal indicator of sex. With a success rate of over 80% for each discriminant function, this method, in addition to the use of linear regression analysis, has the potential to assist the physical anthropologist in their sex determination of an individual. Further research into the variety of conditions found during this study will only increase the accuracy of the method and increase its potential in the process of building a biological profile.

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CHAPTER THREE: DETERMINING ANCESTRY OF THE HYOID FROM THE TERRY COLLECTION USING DISCRIMINANT FUNCTION ANALYSIS

Introduction

The hyoid is generally one of the least represented bones in forensic and archaeological settings involving skeletal remains due to its small size and the possibility that it will be found disarticulated into multiple elements. These factors make it difficult to locate a complete hyoid in both contexts, particularly if the site has been disturbed. However, due to the importance of using every bone available to construct a biological profile, it is necessary to test for size and shape differences of the hyoid between ancestries. Size and shape differences between ancestries may then be used in methods such as discriminant function analysis to determine ancestry of the hyoid.

Ancestry is one of the four defining characteristics of the biological profile that a physical anthropologist constructs when dealing with unidentified skeletal remains and is most accurately predicted using both morphological and metric analyses of elements such as the cranium (Giles and Elliot, 1962; Rhine, 1990) and pelvis and femur (DiBennardo and Taylor, 1983; İşcan, 1983). Perhaps the most commonly used method of estimating ancestry is the use of the computer program FORDISC (Ousley and Jantz, 2005). While these are certainly the most preferred elements to use in ancestry determination, often only a small assemblage of bones is recovered and as a result it is important to develop ancestry determination techniques for as many bones of the body as possible. This study has three main goals regarding ancestry determination of the hyoid. The first is to test the presence of ancestral dimorphism, or differences in size due to differences in ancestry in the hyoids from the Robert J. Terry

Anatomical Collection. The second is to metrically test for differences in shape between African and European hyoids, and the third is to develop a series of discriminant functions that can be used to classify a hyoid as African or European.

Unfortunately there is a lack of research focusing on ancestral differences of the hyoid, making this study the first to approach the subject directly. However, the majority of hyoid studies using metric methods take their measurements from digital imagery, namely radiographs (Jelisiejew et al., 1968; Miller et al., 1998) or digital photographs (Kim et al., 2006). This study differs significantly from others using similar analytical methods in that the measurements were performed on the actual bone using standard osteometric calipers. Using the methods utilized in this study allows the measurements to be easily replicated without needing to take an image of the bone and then take the measurements using some form of computer program. This is also one of the only studies to use the hyoids from a documented anatomical collection rather than hyoids obtained during autopsy. Although the specimens from the Terry Collection may exhibit differential preservation due to handling and the curation process, using specimens that have been macerated and skeletonized has allowed for the measurement of articulated as well as disarticulated hyoids, which is likely to replicate forensic or archaeological situations. This allows for statistical analysis of the size and shape of both articulated and disarticulated hyoids in relation to ancestry.

Because the distinction between ancestry and race is often a contested topic, and the Terry Collection was collected before this distinction was made, it is important to understand how the racial classifications used by Terry and Mildred Trotter translate into the ancestries that physical anthropologists recognize today. In his article, “The American Negro”, Terry uses the phrase “American negro” as an umbrella term to refer to “colored hybrids” (brown) and “pure-blood negroes” (black) and states that although “the hybrid is distinguished biologically from the white and from the negro…society tries to make him a negro; and as a negro he enters into various records which are used as sources for study” (1929: 337). It is apparent from this statement that although an individual may be considered a “hybrid” due to racial admixture, if they closely resemble a “pure-blood negro” it can be assumed that their death records will indicate that they were in fact “negro.” Later Terry defines the term “negro” in relation to individuals within the Terry Collection as “born in the United States and must be considered derivatives of slaves brought to this country from Africa” (1932: 352). While Terry does acknowledge the likely presence of racial admixture within the “negro” population of the collection, he understands that it would be extremely difficult to explicitly determine the genealogy of an individual and that those recorded as being a “negro” or black on their death certificate were of African descent.

Terry did not explain the reasoning behind the use of the term “white” as it applies to the Terry Collection but because the white population was often referred to as “American white” by Mildred Trotter (1951), Terry’s successor as curator of the collection, it is believed that the same principle applies to the white population as applies to the black. In this way the “whites” of the collection are of European descent, although admixture may have occurred, and as such were classified as “white” on their death certificate and when they were added to the collection. For the purposes of this study the currently accepted ancestral terms of African and European will be used to describe the black and white populations that make up the Terry Collection. While a number of studies involving ancestry have been conducted using the Terry Collection (e.g.

DiBennardo and Taylor, 1983; İşcan, 1983; Hefner, 2007), caution should be used when applying results based on this collection to another population (İşcan, 1990).

As one of the four components of the biological profile, physical anthropologists have long been studying skeletal differences that occur between ancestral groups. While these skeletal differences provide no direct evidence for traits generally thought of as racial, such as skin color, they do allow an estimation of original geographic origin of the individual in question (Brace, 1995). Attempts at creating ancestral profiles of populations have allowed for discrimination of more than just the major groups of African, European, and Asian to include populations such as Native American and Hispanic (Komar and Buikstra, 2008). Because of the need to accurately identify skeletal material it is particularly important for forensic anthropologists to recognize these differences and develop methods of classifying material as being of a particular ancestry. The most commonly used methods of ancestry determination are the use of morphoscopic or morphological features, usually of the cranium, that are recorded as categorical data, and entered into the computer program FORDISC which employs a discriminant function approach to classify an unknown individual as being of a particular ancestry (Komar and Buikstra, 2008). The present study was developed to test for size and shape differences of the hyoid of individuals of African and European ancestry in an attempt to develop a discriminant function that could be used in the identification process.

Materials

All hyoids utilized in this study are part of the Robert J. Terry Anatomical Collection, housed at the Smithsonian Institute's National Museum of Natural History (NMNH) in Washington, D.C. The Terry Collection was started in 1898 by Robert J. Terry at the Missouri

Medical College, later becoming part of Washington University Medical School (Hunt and Albanese, 2005). The skeletons were collected from cadavers used in the medical school's anatomy classes and were originally obtained primarily from local St. Louis hospitals and institutional morgues, with a smaller number coming from other institutions around the state of Missouri. The majority of the cadavers were individuals who were not claimed by relatives at local morgues and became property of the state (Hunt and Albanese, 2005). As a result these cadavers usually represented the St. Louis and Missouri lower socioeconomic class. Varying documentation accompanies each skeleton. All individuals have some form of a morgue record that includes basic information such as name, sex, age at death, "race," cause of death, and date of death (Hunt and Albanese, 2005), and most skeletons also include documentation such as dental charts and inventory lists. Currently the Terry Collection consists of 1,728 specimens, 1,607 of which have had their age confirmed and sex and "race" (ancestry) recorded on the morgue record (Hunt and Albanese, 2005).

Of the 1,607 specimens whose age, sex, and ancestry have been confirmed, a total of 398 hyoids (200 males and 198 females) were measured for this study. Unfortunately, because individuals of European ancestry are underrepresented in the Terry Collection only 143 hyoids of European ancestry were measured as opposed to 255 hyoids of African ancestry. Therefore in an attempt to develop an unbiased sample population, 100 hyoids of both African and European ancestry were randomly selected to be used in this study. Within each respective ancestral group, 50 hyoids were articulated, with both greater cornua fused to the body, and 50 were disarticulated, with neither of the greater cornua fused to the body.

Further attempts were made to provide a uniform sample by including as equal numbers of males and females as possible within the subgroups of African and European hyoids. However, as is displayed in Figure 11, the numbers of male and female European hyoids are slightly uneven due to underrepresentation of one or the other. While the number of articulated and disarticulated hyoids, as well as the overall total, remains the same within each ancestral group, the numbers of each sex varies within the European sample. 27 female and 23 male articulated hyoids and 21 female and 29 male disarticulated hyoids comprise the European sample while the African sample consists of 25 of each group.

Although every attempt was made to measure equal numbers of individuals in each ancestral group, preservational differences, in addition to their underrepresentation as a whole, often limited the availability of European hyoids. Of the 398 hyoids used in the study only 143 were of European ancestry and of those many exhibited damage to the greater cornua which later affected how many hyoids could be used to develop the discriminant functions. There are several possible explanations for why Europeans as a whole are underrepresented as well as why the number of European hyoids is substantially less than that of Africans.

The first is that because over 80% of today's current collection had been collected by the time Trotter took over in 1941 (Hunt and Albanese, 2005), the deficiency of whites and females was too great to overcome during her time as curator. It is possible that the majority of the European individuals in the collection were collected earlier in its history and have been subject to the wear and tear of use as teaching specimens as well as the curation process. Also, Trotter attempted to add more "white" skeletons by reinstating 90 that had previously been removed from the collections (Hunt and Albanese, 2005). While this would certainly add to the overall number of European individuals, the condition of the skeletons were most likely not ideal for use in research.

The decade after World War II also had an effect on the demography of the cadavers added to the collection once Trotter took over in 1941 (Hunt and Albanese, 2005). Because of the economic boom after World War II, a higher standard of living was prevalent throughout the United States and more people were affluent enough to be able to claim and bury their family members (Hunt and Albanese, 2005). Also, legal changes involving the willing of bodies to be used in research had an effect on the demography of the cadavers available for anatomical study at Washington University (Hunt and Albanese, 2005), maintaining the significant gap between the numbers of African and European specimens.

In addition, there were a number of specimens that were missing a hyoid despite the fact that the majority of the skeleton was present. This may have been a result of the anatomy students performing the dissection of the cadaver not retaining the hyoid or simply its loss during the maceration and curation process. All of these factors may have led to the underrepresentation and overall poor preservation of European hyoids within the collection. Unfortunately there was not enough time during the data collection process to measure each hyoid so that even those in relatively poor condition were included in the study.

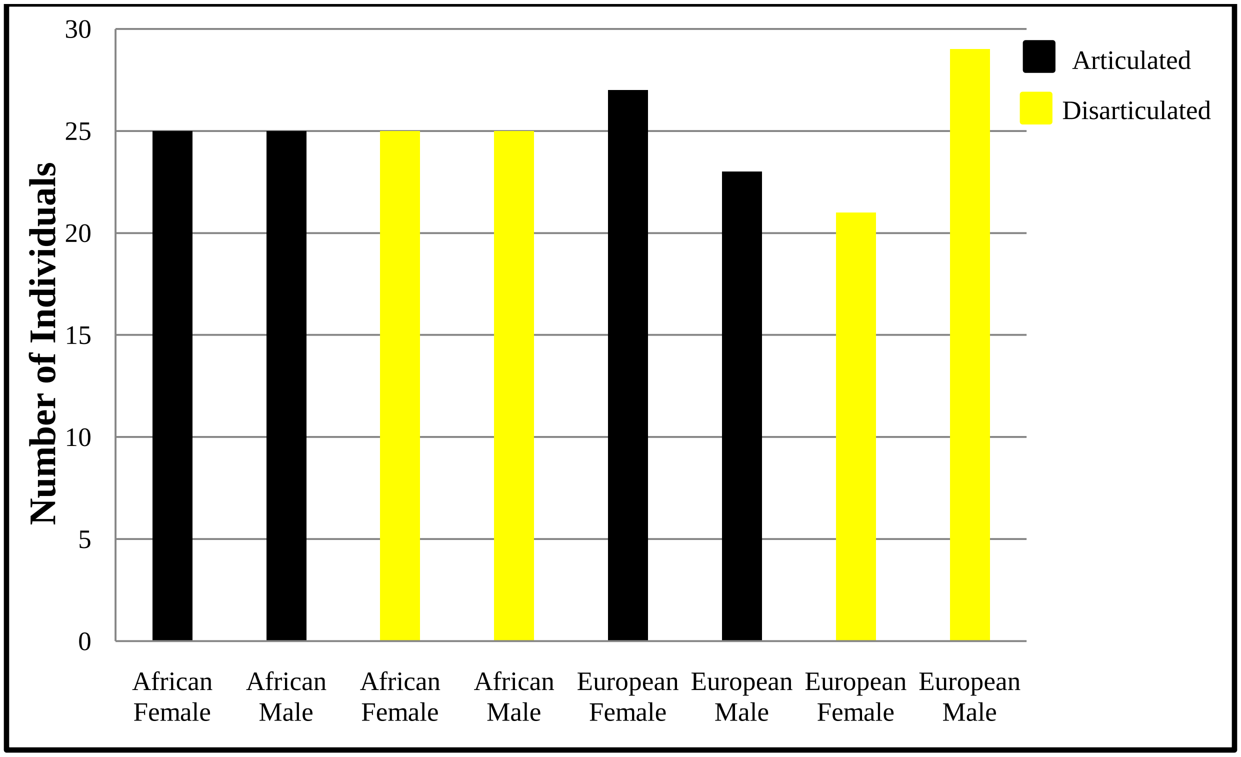

Figure 11. Breakdown of the sample population by ancestry, sex, and whether the hyoid is articulated or disarticulated.

<u>Methods</u>

In an attempt to develop a sampling population that was as uniform as possible, the collection was divided by age, sex, and race. Individuals between the ages of 20 and 79 were broken into groups delineated by 10 year increments, and within these age groups an attempt was made to obtain 20 hyoids from both black and white males and females within that range. Unfortunately, because some groups within the Terry Collection are underrepresented less than 20 hyoids were recovered from individuals within those ranges. In this way, the categorization of the hyoids by age and ancestry was an organizational process used in an attempt to better narrow down those individuals whose hyoids were to be used in the study.

To streamline the data collection process, two sets of measurements were developed to be applied to both the articulated and disarticulated hyoid. Due to the lack of research dealing with ancestry determination of the hyoid, each measurement was chosen because it was thought to demonstrate size differences and it had been used in previous research dealing with sexual dimorphism (Jelisiejew et al., 1968; Miller et al., 1998; Reesink et al., 1999; Lekšan et al., 2005; Shimizu et al., 2005; Kim et al., 2006). These measurements, outlined in Tables 23 and 24, were taken using standard osteometric calipers (Figures 12 and 13). Because it was believed prior to data collection that the preservation of the hyoids would be variable, resulting in the disability to take some measurements, both the right and left sides of each hyoid was measured to maximize the amount of data that would be available for analysis.

Table 24. Articulated hyoid measurements.

Measurement	**Description**
1	Total hyoid length
2	Total hyoid width
3	Maximum length of body
4	Maximum height of body
5	Distance between the distal ends of the right and left greater cornua – taken from lateral edges
6, 7	Maximum length of greater cornua – Right and left
8, 9	Height of greater cornua at articulation point with body – Right and left
10, 11	Width of greater cornua at articulation point with body – Right and left
12, 13	Greatest width of distal end of greater cornua – Left and right
14, 15	Greatest height of distal end of greater cornua – Right and left

Figure 12. Articulated hyoid measurements (NMNH Terry Collection #561).

Table 25. Disarticulated hyoid measurements.

Measurement	**Description**
1	Maximum length of body
2	Maximum height of body
3, 4	Width of greater cornua articulation point with body – Right and left
5, 6	Height of greater cornua at articulation point with body – Right and left
7, 8	Maximum length of greater cornua – Left and right
9, 10	Greatest width of the distal end of the greater cornua – Left and right
11, 12	Greatest height of the distal end of the greater cornua – Right and left

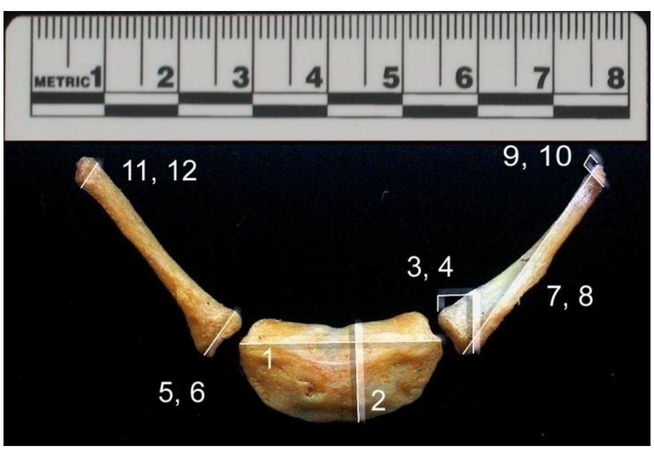

Figure 13. Disarticulated hyoid measurement (NMNH Terry Collection #908).

Three statistical methods were used to determine differences in the size and shape of the hyoid between the two ancestral groups. First, independent samples *t*-tests were used to determine whether differences in size between Africans and Europeans existed and *p*-values below 0.05 were taken to indicate a statistically significant difference in size between ancestries. Second, skeletal measurements were regressed on the geometric mean, which is the sum of all skeletal measurements divided by the total number of measurements, using Least Squares linear regression. This way, when linear regression analysis was applied to each hyoid the residuals indicated differences in shape rather than differences in size. Independent samples *t*-tests were then performed using the residuals of each measurement for Africans and Europeans to test whether the differences in shape were statistically significant.

To further explore shape variation between ancestries, principle component analysis was employed to decompose the metric dataset into a series of size and shape factors. The underlying principle of principle component analysis (PCA) is to represent a multivariate dataset in terms of a smaller number of variables, or factors, allowing them to be better understood (Krzanowski and Marriott, 1994). The PCA reduced the dataset to a series of factors that, in this case, contribute to the overall size and shape differences between ancestries and express how much of the variation is explained by each factor. By studying the correlations between each variable and the factors which are extracted, hypotheses can be devised as to the shapes which are contributing to the variation between groups.

In a morphometrics analysis such as this one the individuals will vary by size and shape so that the first factor, which will explain the most variation, will nearly always account for size while the remaining factors account for shape (Dytham, 1999). Therefore, once the first factor has been removed it is possible to see how much of the remaining variation is due to shape rather than size. The output produced by SPSS expresses each factor in several ways. The first is the eigenvalue which measures the amount of variance among the factors (Dytham, 1999) so that the factor which accounts for the most variance will have the highest eigenvalue with the eigenvalues decreasing as the factors account for less variance. This eigenvalue can then be translated into a percentage that measures how much each factor contributes to the overall variation.

The second important section of the output is the component matrix which displays how each variable is correlated with each factor that is extracted. Examining which variables exhibit strong correlations with the factors that were extracted allows for hypotheses to be developed as to what the shape factors may be. However, the component matrix does not show correlations between variables. This means that, for example, two variables which are strongly correlated with a factor are not necessarily correlated to each other.

Finally, discriminant function analysis was performed in an attempt to develop discriminant functions utilizing a combination of measurements that would have the ability to classify a hyoid as either African or European. In developing the discriminant functions, the significance of each independent variable, or measurement, in the discriminant function analysis was determined using stepwise statistics to find the variables which set the Wilk's lambda at a minimum. The distinction ability of the discriminant function analysis was evaluated by looking at the canonical correlation and eigenvalues so that the higher the canonical correlation and the closer the eigenvalue is to one, the higher the discrimination ability of the function (Kim et al., 2006). The eigenvalue reflects the ratio of importance of the dimensions, in this case the measurements, which classify cases of the dependent variable, or ancestry and is calculated by dividing the "variance within groups" by the "variance between groups" (Kim et al., 2006).

Results

A One-Sample Kolmogorov-Smirnov Test was run for both articulated and disarticulated hyoids to determine whether the data is distributed normally. The test confirmed that the data is distributed normally and therefore, parametric statistical methods, including discriminant function analysis and independent samples *t*-tests, were used in this analysis.

Independent Samples t-test Results

Independent samples *t*-tests performed using the articulated hyoid measurements show statistically significant differences in size between Africans and Europeans for six of the fifteen measurements (Table 25). Those measurements that exhibit significant differences are total hyoid width, maximum length of the body, distance between the distal ends of the right and left greater cornua, the widths of the right and left greater cornua at the articulation point with the body, and the greatest height of the distal end of the left greater cornua. These measurements follow a pattern of the hyoid from European individuals being larger than those from African individuals with the most significant differences being in those measurements dealing with the overall width of the bone such as the length of the body, total hyoid width, and the distance between the greater cornua. Overall, even though only six measurements display statistically significant differences in size, the majority of the average measurements are larger in the European sample than in the African sample, even if by only a slim margin.

Table 26. Average measurements (mm) and p-values of articulated hyoids.

Measurement	African	European	*p* Value
Total hyoid length	35.79 ± 4.07	35.0 ± 4.52	0.376
Total hyoid width	38.90 ± 4.18	42.54 ± 5.12	0.000*
Maximum length of body	21.39 ± 2.99	23.26 ± 2.74	0.002*
Maximum height of body	11.39 ± 1.45	11.31 ± 1.35	0.766
Maximum length of greater cornua, Right	28.95 ± 3.64	29.06 ± 4.10	0.892
Maximum length of greater cornua, Left	28.65 ± 3.39	29.71 ± 3.93	0.211
Distance between distal ends of R and L greater cornua-taken from lateral edges	39.28 ± 5.63	43.48 ± 6.02	0.003*
Height of greater cornua at articulation point with body, Right	7.32 ± 1.06	7.44 ± 1.06	0.629
Height of greater cornua at articulation point with body, Left	7.25 ± 1.04	7.41 ±1.53	0.539
Width of greater cornua at articulation point with body, Right	4.20 ± 0.60	4.52 ± 0.86	0.037*
Width of greater cornua at articulation point with body, Left	4.30 ± 0.74	4.81 ± 1.26	0.015*
Greatest width of distal end of greater cornua, Left	3.14 ± 0.71	3.32 ± 0.97	0.356
Greatest width of distal end of greater cornua, Right	3.24 ± 0.67	3.31 ± 0.83	0.689
Greatest height of distal end of greater cornua, Right	4.04 ± 0.71	4.41 ± 1.03	0.068
Greatest height of distal end of greater cornua, Left	3.97 ± 0.90	4.48 ± 0.79	0.010*

* Statistically significant

Table 26 displays similar results for the *t*-tests performed using the disarticulated hyoid sample. Only three of the 12 measurements, maximum length of the body and widths of the left and right greater cornua at their articulation point with the body, exhibited statistically significant differences between the two ancestral groups. As with the articulated hyoids, these measurements are larger for the European hyoids than African and the majority of the measurements follow this pattern.

Table 27. Average measurements (mm) and p-values of disarticulated hyoids.

Measurement	**African**	**European**	***p* Value**
Maximum length of body	21.69 ± 2.69	23.20 ± 2.86	0.008*
Maximum height of body	11.89 ± 1.51	11.44 ± 1.57	0.149
Width of greater cornua at articulation point with body, Right	3.78 ± 0.58	4.06 ± 0.72	0.042*
Width of greater cornua at articulation point with body, Left	3.61 ± 0.57	4.14 ± 0.85	0.000*
Height of greater cornua at articulation point with body, Right	6.38 ± 0.99	6.37 ± 0.98	0.984
Height of greater cornua at articulation point with body, Left	6.18 ± 1.02	6.49 ± 1.21	0.172
Maximum length of greater cornua, Left	28.80 ± 3.00	29.29 ± 3.91	0.516
Maximum length of greater cornua, Right	29.06 ± 3.28	30.10 ± 3.95	0.200
Greatest width of distal end of greater cornua, Left	3.06 ± 0.51	3.12 ± 0.71	0.632
Greatest width of distal end of greater cornua, Right	3.10 ± 0.54	3.10 ± 0.82	0.981
Greatest height of distal end of greater cornua, Left	4.23 ± 0.78	4.31 ± 0.95	0.666
Greatest height of distal end of greater cornua, Right	4.27 ± 0.77	4.21 ± 0.71	0.731

* Statistically significant

Linear Regression Analyses Results

In addition to the independent samples *t*-tests, linear regression analyses were used to test for differences in shape at the site of each measurement so that negative regression residuals indicated that the shape of the bone for that measurement was relatively smaller in shape than a positive residual. Of the 15 measurements taken from articulated hyoids, eight resulted in negative residuals while seven resulted in positive residuals. Although the regression analysis does not result in a clear pattern of one group having predominately positive or negative residuals, there is a pattern within the groups of each set of measurements having similar residuals. This pattern results in the right and left counterparts of each measurement, and within the same ancestral group, having similar residuals that are opposite those of the other group. For example, measurements six and seven, the widths of the right and left greater cornua at the articulation point with the body, both resulted in negative residuals for African hyoids and positive residuals for European hyoids. This pattern is seen throughout those measurements that have both a right and left component although whether the residual is negative or positive may vary depending on the measurement and ancestry.

After running *t*-tests comparing the mean of each measurement, four measurements were shown to exhibit statistically significant differences in shape between ancestral groups. These measurements are total hyoid length, total hyoid width, maximum length of the body, and the maximum length of the right greater cornua. Refer to Table 27 for a list of regression residuals and their correlating *p*-values and Figure 14 for a visual demonstration of the regression residual for each measurement.

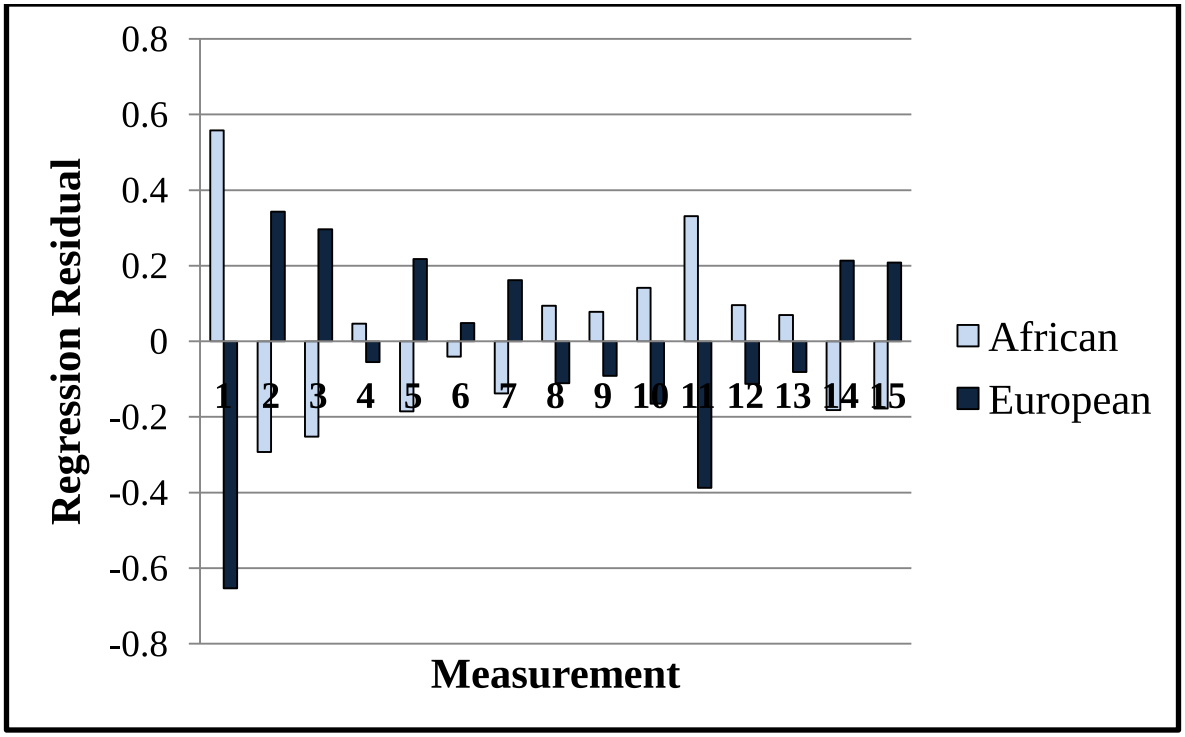

Figure 14. Regression residuals of each measurement for articulated hyoids indicating differences in shape between hyoids of African and European ancestry.

Table 28. Regression residuals and p-values used to demonstrate differences in shape of articulated hyoids.

Measurement	African	European	*p*-Value
Total hyoid length	0.558	-0.654	0.000*
Total hyoid width	-0.293	0.343	0.010*
Maximum length of body	-0.253	0.296	0.027*
Maximum height of body	0.047	-0.055	0.688
Distance between distal ends of R and L greater cornua-taken from lateral edges	-0.185	0.217	0.109
Width of greater cornua at articulation point with body, Right	-0.041	0.048	0.725
Width of greater cornua at articulation point with body, Left	-0.138	0.162	0.234
Height of greater cornua at articulation point with body, Right	0.094	-0.110	0.419
Height of greater cornua at articulation point with body, Left	0.078	-0.092	0.502
Maximum length of greater cornua, Left	0.141	-0.165	0.224
Maximum length of greater cornua, Right	0.331	-0.388	0.003*
Greatest width of distal end of greater cornua, Left	0.096	-0.112	0.410
Greatest width of distal end of greater cornua, Right	0.070	-0.082	0.551
Greatest height of distal end of greater cornua, Right	-0.182	0.214	0.115
Greatest height of distal end of greater cornua, Left	-0.178	0.209	0.124

∗ Statistically significant

When the regression analysis is applied to the disarticulated measurements a pattern similar to that seen in the articulated hyoids is present. With the exception of measurements five and six, the height of the right and left greater cornua at its articulation point with the body, each subset of measurements involving a right and left side display similar residuals that are opposite those of the other ancestral group. However, while the majority of the residuals are similar to those of articulated hyoids, there are three pairs of measurements that display residuals opposite of those seen in the articulated hyoids. These pairs are the height of the right and left greater cornua at the articulation point with the body, the maximum length of the right and left greater cornua, and the height of the distal ends of the right and left greater cornua. Figure 15 displays the residuals of disarticulated hyoids.

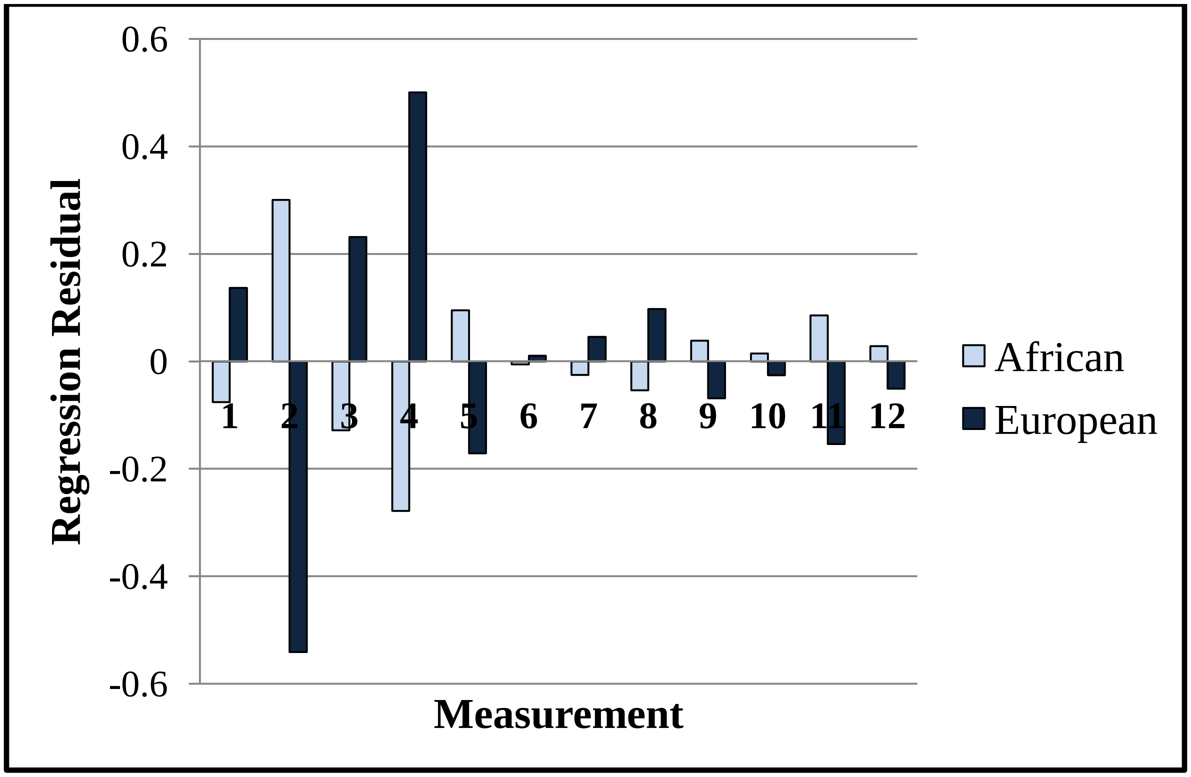

Figure 15. Regression residuals of each measurement for disarticulated hyoids indicating differences in shape between hyoids of African and European ancestry.

After running *t*-tests comparing the residual of each measurement, only two measurements were shown to exhibit statistically significant differences in shape between ancestral groups. These measurements are maximum height of the body and the width of the left greater cornua at its articulation point with the body. Refer to Table 28 for a list of regression residuals and their correlating *p*-values.

Table 29. Regression residuals and p-values used to demonstrate differences in shape of disarticulated hyoids.

Measurement	**African**	**European**	***p*-Value**
Maximum length of body	-0.076	0.137	0.395
Maximum height of body	0.301	-0.541	0.000*
Width of greater cornua at articulation point with body, Right	-0.129	0.231	0.147
Width of greater cornua at articulation point with body, Left	-0.278	0.501	0.001*
Height of greater cornua at articulation point with body, Right	0.095	-0.171	0.285
Height of greater cornua at articulation point with body, Left	-0.006	0.0102	0.949
Maximum length of greater cornua, Left	-0.025	0.045	0.778
Maximum length of greater cornua, Right	-0.054	0.097	0.545
Greatest width of distal end of greater cornua, Left	0.038	-0.069	0.668
Greatest width of distal end of greater cornua, Right	0.014	-0.026	0.87
Greatest height of distal end of greater cornua, Right	0.085	-0.154	0.338
Greatest height of distal end of greater cornua, Left	0.028	-0.051	0.751

* Statistically significant

Principle Component Analysis Results

Principle component analysis performed on articulated hyoids produced four factors with eigenvalues over 1.0 (Table 29) indicating they contributed to the majority of variance among individuals. Component 1, with an eigenvalue of 6.357, contributed 42.381% of the factor variance, indicating it is representative of size. Therefore this component will be ignored and factors two, three, and four will be focused on as indicators of shape differences. Component two contributes the most variance of the remaining components with 13.946%, component three contributed 9.919% of the total variance, and component four contributed 8.183% of total variance.

Table 30. Total variance explained by each of the four components extracted by the principle component analysis.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.357	42.381	42.381	6.357	42.381	42.381
2	2.092	13.946	56.328	2.092	13.946	56.328
3	1.488	9.919	66.247	1.488	9.919	66.247
4	1.227	8.183	74.429	1.227	8.183	74.429

Extraction Method: Principal Component Analysis.

Discriminant Function One

In using stepwise statistics to develop the discriminant functions each step was statistically significant at p = 0.000. For articulated hyoids, four variables combine to result in the lowest Wilk's lambda. These variables are total length of the hyoid (Measurement 1), maximum length of the body (Measurement 3), the maximum length of the left greater cornua (Measurement 10), and the height of the distal end of the right greater cornua (Measurement 14).

The discrimination ability of the function is high with a canonical correlation of 0.790, an eigenvalue of 1.655, and Wilk's lambda of a canonical discriminant function was 0.000. These values indicate that the function is producing statistically significant discriminant function scores between the hyoids of African and European ancestry.

A discriminant function utilizing the four variables, their unstandardized discriminant coefficients, and the constant produces the discriminant score for each hyoid. See Table 30 for a summary of the unstandardized coefficients for each variable and the constant for articulated hyoids. The discriminant function will hereafter be referred to as Function 1 and is as follows:

$$\text{Discriminant score (D)} = (-0.535)(X_1) + (0.350)(X_2) + (0.443)(X_3) + (0.780)(X_4) - 4.867$$

If the resulting discriminant score is above the cutoff point of 0.101, which is the mean of the average discriminant scores for both African and European hyoids, the individual is likely to be European while if the score is below the cutoff point the individual is likely to be African. In the classification results, a total of 85.3% of African and 93.1% of European hyoids were correctly classified while a total of 88.9% of total cases were classified correctly based on this function (Table 31). Figure 16 displays the distribution of discriminant scores for the 63 African and European articulated hyoids that were used to test Function 1.

Table 31. Unstandardized discriminant function coefficients of articulated hyoids used to develop Function 1.

Measurement	**Unstandardized Discriminant Function Coefficients**
1 (X_1)	-0.535
3 (X_2)	0.350
10 (X_3)	0.443
14 (X_4)	0.780
Constant	-4.867

Table 32. Probabilities of group membership of articulated hyoids used to test Function 1.

		Ancestry	Predicted Group Membership .00	1.00	Total
Original	Count	.00	29	5	34
		1.00	2	27	29
	%	.00	85.3	14.7	100.0
		1.00	6.9	93.1	100.0

a. 88.9% of original grouped cases correctly classified.

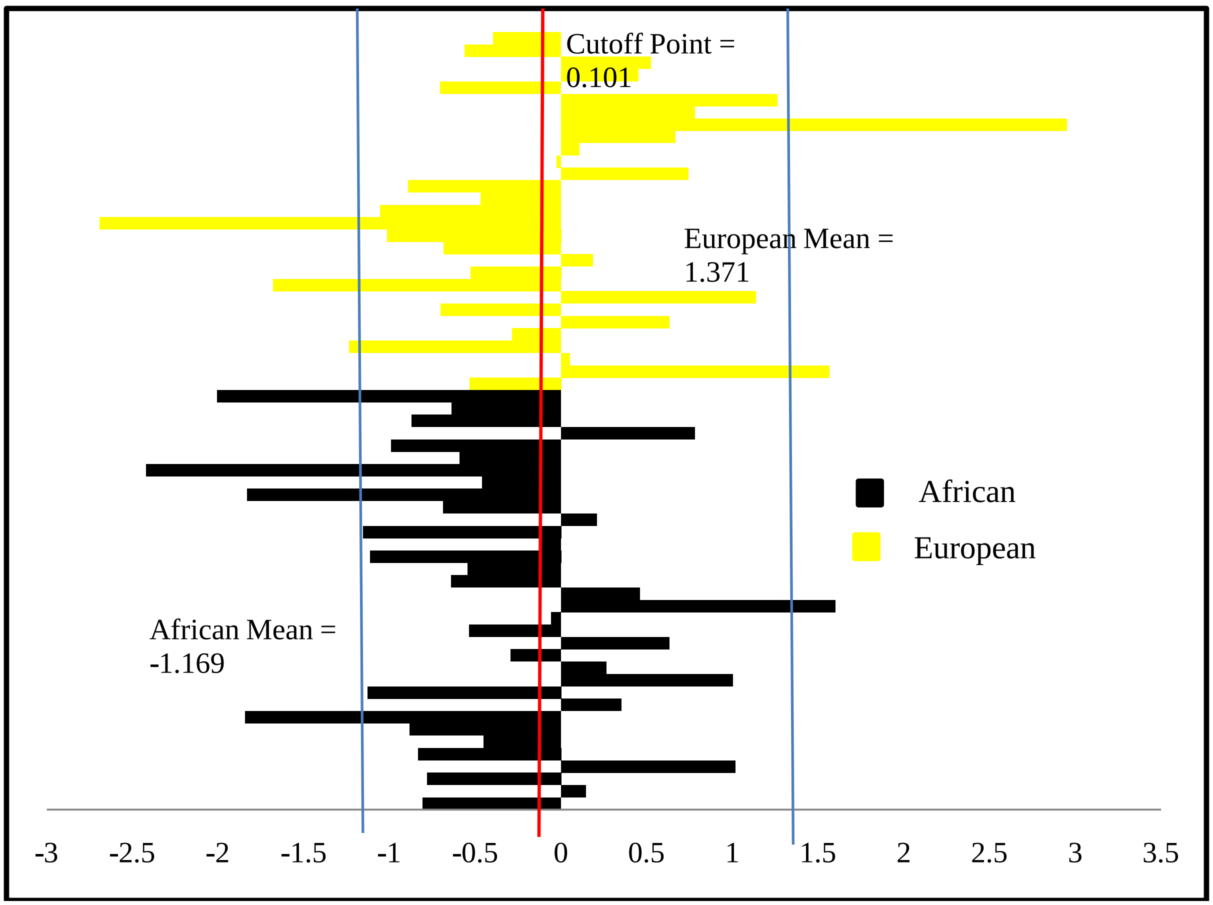

Figure 16. Distribution of discriminant scores for articulated African and European hyoids used to test Function 1.

Discriminant Function Two

Once the stepwise statistical method had been applied to the sample population of disarticulated hyoids, only two variables combined to offer the lowest Wilk's lambda value. These variables are maximum height of the body (Measurement 2) and the width of the left greater cornua at its articulation point with the body (Measurement 4). The discrimination ability of the function is very low with a canonical correlation of 0.516, an eigenvalue of 0.362, and Wilk's lambda of a canonical discriminant function was 0.000. These values indicate that the function is producing statistically significant discriminant function scores between the groups of Africans and Europeans but that the discriminating ability of the function is low.

A discriminant function utilizing the two variables, their unstandardized discriminant coefficients, and the constant produces the discriminant score for each disarticulated hyoid. See Table 32 for a summary of the unstandardized coefficients for each variable and the constant for articulated hyoids.

The discriminant function will from now on be referred to as Function 2 and is as follows:

$$\text{Discriminant score (D)} = (-0.440)(X_1) + (1.483)(X_2) - 0.577$$

If the resulting discriminant score is above the cutoff point of 0.177, which is the mean of the average discriminant scores for both African and European hyoids, the individual is likely to be European while if the score is below the cutoff point the individual is likely to be African. In the classification results, a total of 74% of African and 55.1% of Europeans were correctly classified based on this function while a total of 64.6% of total classes were correctly classified

(Table 33). Figure 17 displays the distribution of discriminant scores for the 99 disarticulated hyoids that were used to test Function 2.

Table 33. Unstandardized discriminant function coefficients of disarticulated hyoids used to develop Function 2.

Measurement	**Unstandardized Discriminant Function Coefficients**
2 (X_1)	-0.440
4 (X_2)	1.483
Constant	-0.577

Table 34. Probabilities of group membership of disarticulated hyoids used to test Function 2.

			Predicted Group Membership		
		Ancestry	.000	1.000	Total
Original	Count	.000	37	13	50
		1.000	22	27	49
	%	.000	74.0	26.0	100.0
		1.000	44.9	55.1	100.0

a. 64.6% of original grouped cases correctly classified.

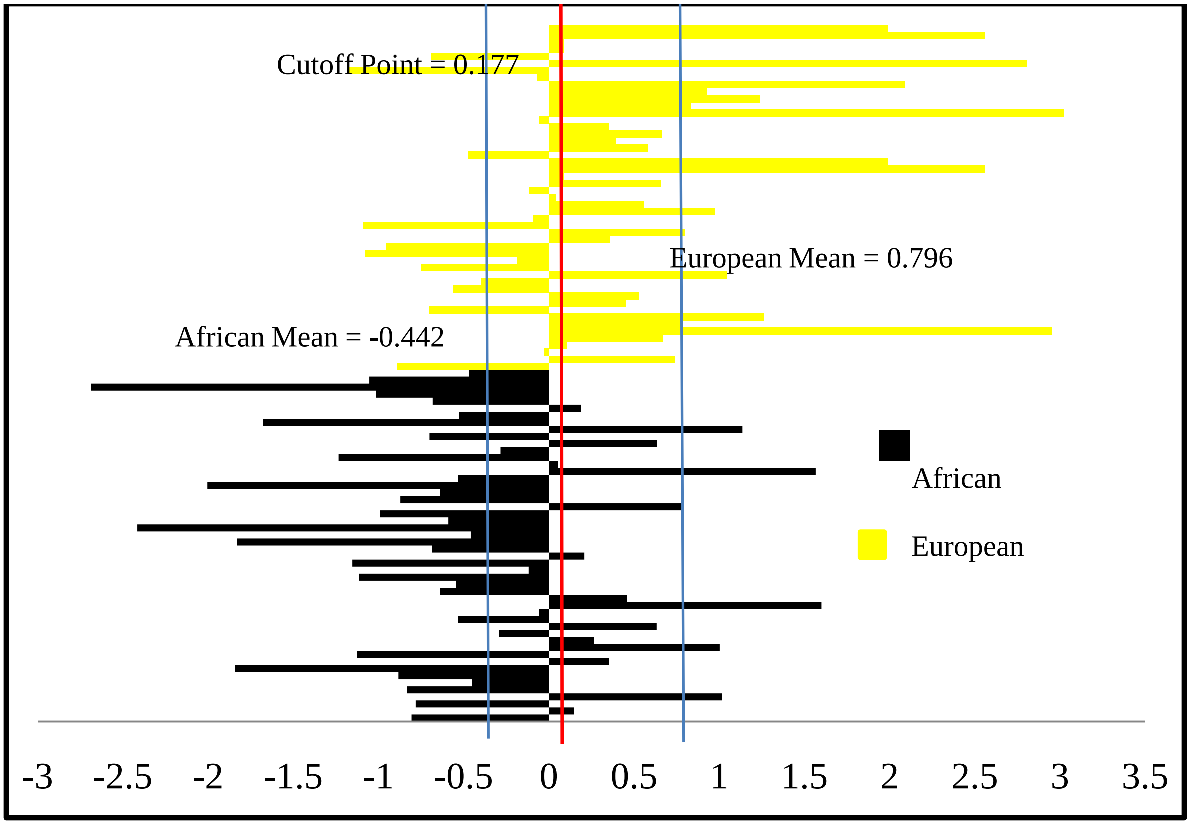

Figure 17. Distribution of discriminant scores for African and European disarticulated hyoids used to test Function 2.

Discriminant Function Three

Finally, a discriminant function was developed using only those 12 measurements that both the articulated and disarticulated hyoids had in common. Stepwise statistics produced three measurements that combined to produce the lowest Wilks' lambda. These measurements are the maximum length of the body (Measurement 3 of articulated and 1 of disarticulated hyoids), maximum height of the body (Measurement 4 of articulated and 2 of disarticulated hyoids), and the width of the left greater cornua at articulation point with the body (Measurement 7 of articulated and 4 of disarticulated hyoids).

The discrimination ability of this function is very low with a canonical correlation of 0.499 and an eigenvalue of 0.331. The Wilks' lambda of a canonical discriminant function is still 0.000, indicating that the function is producing statistically significant discriminant function scores between the groups of African and European hyoids.

A discriminant function utilizing the three variables, their unstandardized discriminant coefficients, and the constant produces the discriminant score for each hyoid. See Table 34 for a summary of the unstandardized coefficients for each variable and the constant for articulated hyoids. The discriminant function will from now on be referred to as Function 3 and is as follows:

$$\text{Discriminant score (D)} = (0.325)(X_1) + (-0.601)(X_2) + (0.691)(X_3) - 3.169$$

If the resulting discriminant score is above the cutoff point of 0.1095, which is the mean of the average discriminant scores for both Africans and Europeans, the individual is likely to be European while if the score is below the cutoff point the individual is likely to be African. In the classification results, a total of 72.7% of African and 67.3% of European hyoids and 70.1% of total cases were correctly classified based on this function (Table 35). Figure 18 shows the discriminant scores for the sample population used to develop Function 3.

Table 35. Unstandardized discriminant function coefficients of both articulated and disarticulated hyoids used to develop Function 3.

Measurement	**Unstandardized Discriminant Function Coefficients**
3; 1 (X_1)	0.325
4; 2 (X_2)	-0.601
7; 4 (X_3)	0.691
Constant	-3.169

Table 36. Probabilities of group membership of articulated and disarticulated hyoids used to test Function 3.

		Ancestry	Predicted Group Membership .00	1.00	Total
Original	Count	.00	72	27	99
		1.00	32	66	98
	%	.00	72.7	27.3	100.0
		1.00	32.7	67.3	100.0

a. 70.1% of original grouped cases correctly classified.

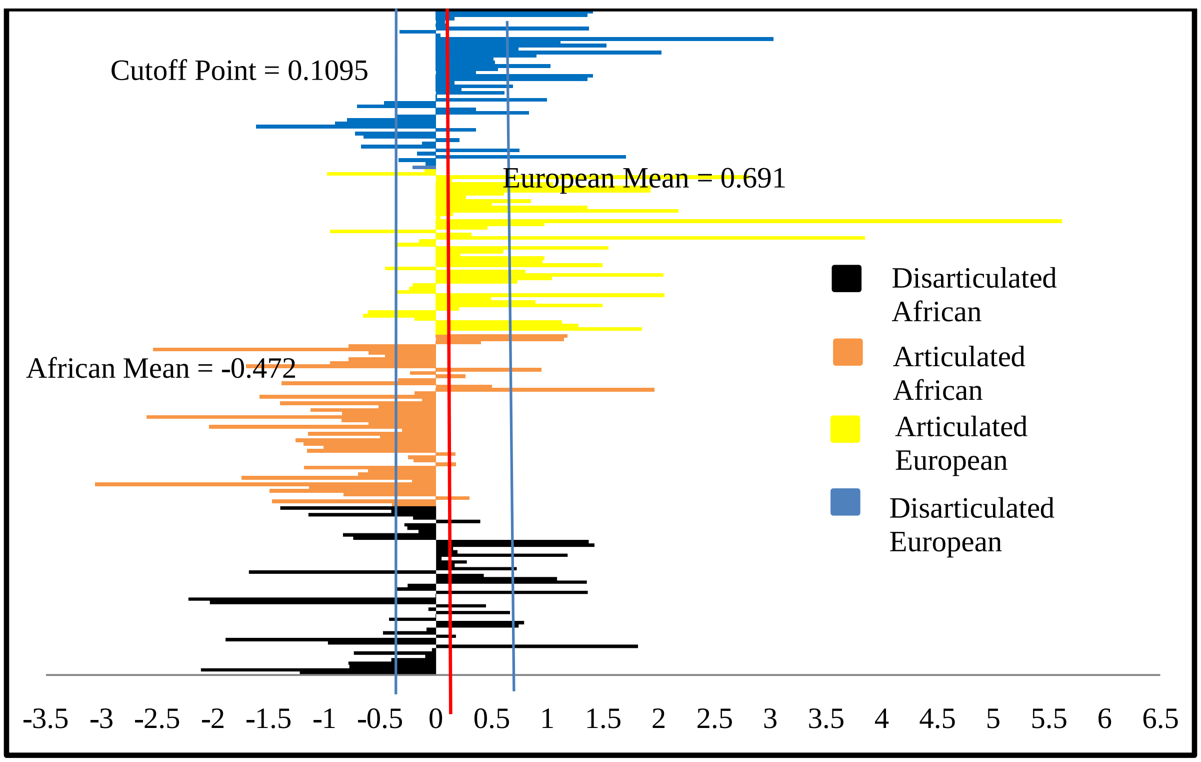

Figure 18. Distribution of discriminant scores for articulated and disarticulated African and European hyoids used to test Function 3.

Discriminant Function Four

Because the chances are good that a recovered hyoid will be disarticulated and possibly damaged, it is most likely that the hyoid body will be in the best condition to use in a discriminant function. Therefore a fourth function was developed using only the two measurements taken of the body of disarticulated hyoids in an attempt to test the usefulness of just the body in determining ancestry. Once the stepwise statistical method had been applied to the sample population of disarticulated hyoids, the discrimination ability of the function is relatively low with a canonical correlation of 0.379 and an eigenvalue of 0.524. However, the Wilks' lambda of a canonical discriminant function is still 0.000, indicating that the function is producing statistically significant discriminant function scores between the groups of African and European hyoids.

A discriminant function utilizing the two variables, their unstandardized discriminant coefficients, and the constant produces the discriminant score for each disarticulated hyoid. See Table 36 for a summary of the unstandardized coefficients for each variable and the constant for those disarticulated hyoids.

The discriminant function will from now on be referred to as Function 4 and is as follows:

$$\text{Discriminant score (D)} = (0.542)(X_1) + (-0.901)(X_2) - 1.657$$

If the resulting discriminant score is above the cutoff point of 0.00, which is the mean of the average discriminant scores for both males and females, the individual is likely to be European while if the score is below the cutoff point the individual is likely to be African. In the classification results, a total of 74% of African and 72% of European hyoids were correctly classified based on this function while a total of 73% of total classes were correctly classified

(Table 37). Figure 19 displays the distribution of discriminant scores for the 100 disarticulated hyoids that were used to develop Function 4.

Table 37. Unstandardized discriminant function coefficients of disarticulated hyoids used to develop Function 4.

Measurement	**Unstandardized Discriminant Function Coefficients**
1 (X_1)	0.542
2 (X_2)	-0.901
Constant	-1.657

Table 38. Probabilities of group membership of disarticulated hyoids used to test Function 4.

			Predicted Group Membership		
		Ancestry	.000	1.000	Total
Original	Count	.000	37	13	50
		1.000	14	36	50
	%	.000	74.0	26.0	100.0
		1.000	28.0	72.0	100.0

a. 73.0% of original grouped cases correctly classified.

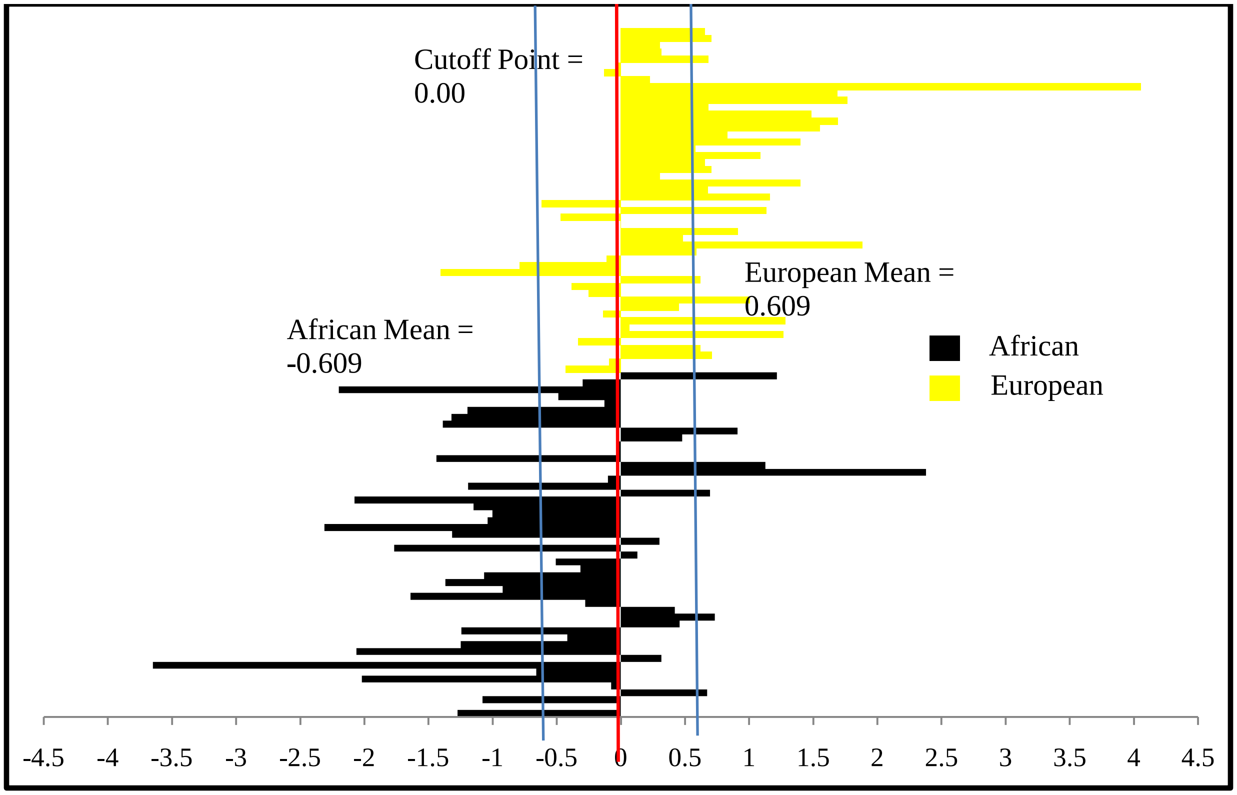

Figure 19. Distribution of discriminant scores for disarticulated African and European hyoid bodies used to test Function 4.

Unfortunately, because of the differential preservation of the hyoids in the Terry Collection not all of the measurements could actually be taken from each bone. This led to the exclusion of some hyoids in the discriminant function analysis process so that not all of the 200 articulated and disarticulated hyoids were used because they were missing a measurement that was a part of the equation. Table 38 lists the sample size used in each analysis and the resulting discriminant function. It is important to note that the classification statistics for Functions 1 and 2 were results of testing the functions on just the isolated articulated and disarticulated samples while Function 3 was tested using the entire sample population of 200 hyoids and Function 4 was developed using the sample of 100 disarticulated hyoids.

Table 39. Summary of the sample population used to test each discriminant function and its overall accuracy.

Discriminant Function	**Sample**	**Accuracy of Function**
Function 1	63 articulated: 34 African; 29 European	88.9%
Function 2	99 disarticulated: 50 African; 49 European	64.6%
Function 3	197 articulated and disarticulated: 99 African; 98 European	70.1%
Function 4	100 disarticulated: 50 African; 50 European	73.0%

Discussion

Using the Discriminant Functions

The purpose of developing four different discriminant functions is to provide multiple opportunities for the physical anthropologist to classify a hyoid as either African or European regardless of whether the greater cornua are fused to the body. Therefore these functions are best used in conjunction with each other so that a determination of ancestry is not based on one single function. If a fully articulated hyoid is recovered the best function to use would be Function 1 because it was developed based on a sample population composed solely of articulated hyoids. However, Functions 3 and 4 should also be used because it utilizes measurements that both disarticulated and articulated hyoids have in common. The same is true of a recovered disarticulated hyoid. The best function to use would be Function 2 which was developed using only a sample of disarticulated hyoids, but Function 3 should also be used because it is based on measurements that articulated and disarticulated hyoids have in common and Function 4 was developed using only the body of disarticulated hyoids. If only the hyoid body is recovered the best function to use would be Function 4 because it was developed specifically to be used to determine ancestry of a body. Using multiple functions will allow for better accuracy when determining ancestry. Tables 39, 40, 41, and 42 compile the measurements and discriminant score for each function.

It is also important to note that although the left and right measurements were used separately to develop the discriminant functions, they can be interchangeable if the necessary element is not present. So, for example, if a hyoid body and right greater cornua are recovered, Functions 2, 3, and 4 can all still be utilized by substituting the measurements which are supposed to be taken of the left greater cornua with measurements taken of the right greater cornua. This interchangeability was determined by testing the accuracy of discriminant function analysis using the right and left measurements separately. The analyses were extremely close in accuracy, for both articulated and disarticulated hyoids, suggesting the left or right measurements can be substituted for the one that is missing.

Table 40. A compilation of the information needed to use Function 1.

Discriminant score (D) = $(-0.535)(X_1) + (0.350)(X_2) + (0.443)(X_3) + (0.780)(X_4) - 4.867$	
Measurement	Total hyoid length (X_1) Maximum length of the body (X_2) Maximum length of the left greater cornua (X_3) Height of the distal end of the right greater cornua (X_4)
Cutoff Point	0.101 Above: Likely European Below: Likely African

Table 41. A compilation of the information needed to use Function 2.

Discriminant score (D) = (-0.440)(X_1) + (1.483)(X_2) – 0.577	
Measurement	Maximum height of the body (X_1) Width of left greater cornua at articulation point with the body (X_2)
Cutoff Point	0.177 Above: Likely European Below: Likely African

Table 42. A compilation of the information needed to use Function 3.

Discriminant score (D) = (0.325)(X_1) + (-0.601)(X_2) + (0.691)(X_3) – 3.169	
Measurement	Maximum length of body (X_1) Maximum height of body (X_2) Width of left greater cornua at articulation point with body (X_3)
Cutoff Point	0.1095 Above: Likely European Below: Likely African

Table 43. A compilation of the information needed to use Function 4.

Discriminant score (D) = (0.542)(X_1) + (-0.901)(X_2) – 1.657	
Measurement	Maximum length of body (X_1) Maximum height of body (X_2)
Cutoff Point	0.00 Above: Likely European Below: Likely African

Articulated Hyoid Size and Shape

The data presented in the results section suggest several differences in hyoid size and shape occur between those of African and European ancestries. Although the majority of the differences are not statistically significant, those that are give some insight into possible overall differences. When looking exclusively at articulated hyoids, there are three measurements which display statistically significant differences that could be indicators of overall differences in shape. In all three measurements - total hyoid width, maximum length of the body, and width between the distal ends of the greater cornua - the European hyoid is wider by a significant amount.

Of these three, the maximum length of the body could be the contributing factor as to why the total width and distance between the distal ends of the greater cornua is statistically significant between European and African hyoids in size. Because the lengths of both right and left greater cornua are relatively similar, it seems unlikely that they would be major contributors to the overall size and shape differences. In addition, the length of the body remains one of only three measurements taken on disarticulated hyoids that is dimorphic so that the difference in size is likely not a product of ossification of the greater cornua to the body. This also leads to the possibility that the length of the hyoid body is one of the most dimorphic indicators of the hyoid which is why it is used in three of the four discriminant functions produced from this study.

The linear regression analyses of articulated hyoids show that although there are no major differences between the two groups at particular measurement sites, those that are associated with or contribute to the overall shape of the bone are the measurements that are found to have significant shape differences. These include total length, total width, and maximum length of the body. This suggests that not only can shape differences between African and European hyoids be seen when it is fully articulated, but that the shape differences seen in the overall hyoid are not a product of shape differences of individual measurements. The exception to this statement is the maximum length of the body which likely contributes to the statistically significant difference in total width in both size and shape.

Two interesting patterns emerge through the linear regression analysis of articulated hyoids once the African and European hyoids have been scaled to the same size and the regression residuals are used to identify differences in shape between ancestries. The first pattern is that the negative residual produced for total hyoid length in European hyoids versus the positive residual for African hyoids indicates that European hyoids are shorter in total length once both hyoids have been reduced to the same size. The difference between the two residuals is statistically significant. This is particularly interesting because the difference in total hyoid length, in terms of size, was not found to be statistically significant, suggesting the shape of the greater cornua varies between the ancestries while the length does not. It may be possible that the greater cornua of European hyoids exhibit more lateral projection at their midpoint but also more medial curvature of the distal end while the African hyoids tend to exhibit a straighter shape.

This difference in shape also corresponds with the second pattern that has been noted which is that African hyoids are overall narrower in total hyoid width than Europeans. This is seen by the statistically significant difference between the negative residual produced for African hyoids and positive residual produced for European hyoids. These shape differences are also seen in the independent samples *t*-test results in which Europeans were found to be significantly wider than African hyoids. Again, this could be due to more lateral bowing of the greater cornua in European hyoids whereas the greater cornua of African hyoids tend to be straighter.

The difference in total width may also be due to the differences in hyoid body length so that the longer hyoid body results in a wider overall size and shape regardless of the length or shape of the greater cornua. Both the independent samples *t*-tests and the linear regression analyses indicate that European hyoids are longer and wider than African hyoids. Even if the greater cornua of an African and European hyoid were the same length and had the same amount of curvature, the hyoid with the longer body would likely end up with a larger overall width.

The regression analyses also show an interesting pattern when looking at the regression means and what they can say about possible shape differences. Those measurements that are paired, meaning they have a right and left component, exhibit similar means that are opposite in value those of the opposite ancestry. While most of the differences are not significant, this could indicate slight shape differences at the site of the measurement. If the right and left sides varied from one another then it would seem as if there was no pattern, that the differences would be somewhat random or that the hyoids were very asymmetrical. However, because we see this pattern in most sets of measurements, in both articulated and disarticulate hyoids, it seems unlikely that it would be random.

The principle component analysis performed using the sample of articulated hyoids suggests several of the same shape patterns discussed in the preceding paragraphs. In looking at the component matrix (Table 43), the two variables that are most strongly correlated with component two are total width of the hyoid and the distance between the distal ends of the left and right greater cornua. Because these two measurements, when taken together, provide an idea of the width of the hyoid, it is believed that component two represents hyoid width and therefore width of the hyoid is the most influential factor besides size which contributes to the variation between ancestries. Component three exhibits strong correlations with each of the four measurements taken at the distal end of the greater cornua, suggesting it is a measure of gracility or lack of robusticity. This could indicate that shape variation between the two ancestries is partially due to overall differences in size, with one ancestry being less robust or smaller than the other. When each measurement is studied there is an overall trend that European hyoids are on average slightly larger than African. Finally, the fourth component is strongly correlated with three measurements: total hyoid length and maximum length of the right and left greater cornua. When taken together these three measurements describe the length of the hyoid, suggesting component four refers to the length of the hyoid so that one ancestral group may be shorter than the other. However, because it contributes so little to the variation between groups, a significant difference in the length of hyoids between groups is not observable.

Table 44. Component matrix displaying correlations between each measurement and the four components that were extracted using principle component analysis.

	Component			
	1	2	3	4
TotalLength	.780			-.410
TotalWidth	.583	.610		
MaxLengthBody	.601			.502
MaxHeightBody	.568			
RLDistance		.764		
WidthGCR	.643	-.482		
WidthGCL	.642	-.415		
HeightGCR	.720	-.418		
HeightGCL	.713	-.475		
MaxLengthGCL	.762			-.463
MaxLengthGCR	.808			-.446
DistalWidthL	.593		.536	
DistalWidthR	.687		.410	
DistalHeightR	.618		.528	
DistalHeightL	.550		.508	

Extraction Method: Principal Component Analysis.

a. 4 components extracted.

Previous Research

Unfortunately the body of research focusing on ancestral differences in the hyoid is extremely limited. Kim and colleagues state that based on their research involving sexual dimorphism within a sample of Korean hyoids, “the hyoid…will prove helpful in distinguishing them from other populations” (2006: 984). This statement was based on a comparison between their measurements and those of a previous 1998 study by Miller, Walker, and O’Halloran (1998) where size differences for a number of measurements were obvious. The sample used by Miller and colleagues was composed of mostly “Whites and Hispanics” (1998: 1138) and for many of the measurements that the two studies have in common there are significant differences. This is an indication that size differences between populations could be used to distinguish between the two groups although Kim and colleagues do not propose a method for doing so. Tables 44 and 45 present those measurements that the two previously mentioned studies have in common with this study to demonstrate size differences between the groups that could be used to distinguish between them.

Table 45. Comparison of the average measurements of articulated African hyoids from this study and those from Miller et al. (1998) and Kim et al. (2006).

Measurement	**Miller et al, 1998**		**Kim et al., 2006**		**Present study (2009)**	
	Male	Female	Male	Female	Male	Female
Maximum length of body	35.2 ± 5.8	19.4 ± 3.0	25.5 ± 2.9	21.4 ± 3.6	23.0 ± 2.2	19.7 ± 2.8
Maximum length of left greater cornua	21.4 ± 3.4	27.7 ± 4.3	34.9 ± 3.1	30.3 ± 3.0	29.2 ± 3.4	28.0 ± 3.4
Maximum length of right greater cornua	28.5 ± 5.2	27.3 ± 4.4	35.6 ± 3.6	31.2 ± 2.8	29.8 ± 3.2	28.2 ± 3.9
Width of left greater cornua at articulation point with body	5.0 ± 1.2	4.7 ± 0.9	5.4 ± 0.8	4.3 ± 0.9	4.4 ± 0.5	4.2 ± 0.9
Width of right greater cornua at articulation point with body	5.1 ± 1.1	4.7 ± 1.0	5.6 ± 0.9	4.5 ± 0.8	4.3 ± 0.4	4.1 ± 0.7
Total length			39.4 ± 3.6	33.9 ± 4.0	37.1 ± 4.1	34.6 ± 3.7
Distance between distal ends of right and left greater cornua			48.3 ± 5.9	41.4 ± 6.1	41.0 ± 5.3	37.6 ± 5.6

Table 46. Comparison of the average measurements of articulated European hyoids from this study and those from Miller et al. (1998) and Kim et al. (2006).

Measurement	Miller et al, 1998		Kim et al., 2006		Present study (2009)	
	Male	Female	Male	Female	Male	Female
Maximum length of body	35.2 ± 5.8	19.4 ± 3.0	25.5 ± 2.9	21.4 ± 3.6	24.5 ± 2.7	22.1 ± 2.3
Maximum length of left greater cornua	21.4 ± 3.4	27.7 ± 4.3	34.9 ± 3.1	30.3 ± 3.0	31.7 ± 3.3	27.1 ± 3.2
Maximum length of right greater cornua	28.5 ± 5.2	27.3 ± 4.4	35.6 ± 3.6	31.2 ± 2.8	31.3 ± 3.5	26.5 ± 3.2
Width of left greater cornua at articulation point with body	5.0 ± 1.2	4.7 ± 0.9	5.4 ± 0.8	4.3 ± 0.9	5.2 ± 1.6	4.5 ± 0.8
Width of right greater cornua at articulation point with body	5.1 ± 1.1	4.7 ± 1.0	5.6 ± 0.9	4.5 ± 0.8	4.8 ± 0.9	4.2 ± 0.7
Total length			39.4 ± 3.6	33.9 ± 4.0	37.9 ± 3.4	31.9 ± 3.4
Distance between distal ends of right and left greater cornua			48.3 ± 5.9	41.4 ± 6.1	44.5 ± 5.9	42.5 ± 6.1

From Tables 44 and 45 it is apparent that size differences do exist between the sample populations used in these three studies but that some measurements exhibit more significant differences than others. With the exception of maximum length of the body, the Korean sample used by Kim et al. (2006) tends to have larger averages than those presented by Miller et al. (1998) and in this study although they are closer to those of the European sample used in this study. Because 96% of the sample used by Miller et al. (1998) was made up of Whites and Hispanics it was expected that this sample would produce averages similar to the European population used in this study. However, for some of the measurements such as maximum length of the body and maximum length of the greater cornua the differences between the two populations was significant. This could be due to different measurement techniques - Miller et al. (1998) took radiographs of each hyoid first, converted them to digital images, and took measurements from the image, - variation in the measurements due to the inclusion of the Hispanic population, or the inclusion by Miller et al. of hyoids that, if skeletonized, may not be fully articulated. Despite the differences between these two samples, they are still closer in value to each other than to the Korean sample, suggesting it may be possible to develop a method of discriminating between the two groups. Unfortunately the Terry Collection only has five Asian skeletons so that including Asian individuals in this study was not possible.

Accuracy Comparison of Ancestry Determination Methods

Possibly the most preferred method of ancestry estimation is the use of morphological characteristics of the skull, particularly the midfacial region, whose form varies between populations. Due to these morphological differences between populations of different ancestries, variations in specific characteristics can be both visually assessed or, if enough of the skull is present, metrically determined. Many physical anthropologists prefer non-metric evaluation of skull traits such as nasal aperture width, interorbital breadth, or palate shape, because it does not require measurement equipment or computer programs and there are a wide variety of traits that can be assessed (Rhine, 1990). Unfortunately this method requires extensive experience in dealing with non-metric traits so that the anthropologist assessing ancestry is familiar with traits to look for and the slight variations that exist between populations. For this reason a number of metric methods, in addition to the creation of the computer program FORDISC, have been developed in an attempt to provide objective, unbiased modes of estimating ancestry that can be easily utilized by an inexperienced user. A number of discriminant functions have been developed using measurements of the skull but other studies have used postcranial elements such as the pelvis and femur (DiBennardo and Taylor, 1983; İşcan, 1983). Varying degrees of accuracy have been found using metric methods, indicating a need for further investigation of ancestral differences for postcranial elements.

Likely the most widely used metric method of determining ancestry is through the use of FORDISC, a computer program that uses statistical discrimination to determine whether an unknown individual's biological profile, consisting of a series of cranial and postcranial measurements, is consistent with a particular group (Ousley et al., 2006). The discriminant functions utilized by FORDISC rely on modern reference groups that are part of the Forensic Data Bank (FDB) which is a collection of modern forensic data from recent cases (Ousley and Jantz, 1998). The FDB consists of metric and non-metric observations from each case (Ousley and Jantz, 1998) so that not only is each individual described by a series of cranial and postcranial measurements, depending upon how much of the skeleton is present, but also the circumstances surrounding the case and the condition of the remains. At the time of FORDISC's most recent update the FDB consisted of over 2,900 cases entered with over 1,800 having definite sex and race and a further 1,731 being positively identified (Forensic Anthropology Center, 2005). Demographic analysis of the FDB has shown that the American population has changed significantly since the Terry and Hamman-Todd Collections have been amassed due to nutritional differences and reduced skeletal stress so that although these reference collections are still valuable research tools, the FDB is a more accurate representation of the modern American population (Ousley and Jantz, 1998).

The use of discriminant function analysis as the method of sex and ancestry discrimination has allowed for easy use, even by users who are unfamiliar with the program. A series of cranial and postcranial measurements of the unknown individual are entered into the program and the discriminant functions convert the measurements into a discriminant score (Ousley and Jantz, 2005). The score of the unknown individual is then compared to the average score for each reference group and is classified with the group with the closest score (Ousley and Jantz, 2005). The likelihood that the unidentified remains belong to a particular reference group is calculated using two different probabilities: posterior and typicality. The posterior probability is a measure of the likelihood that the individual belongs to the group with which it was classified, while the typicality probability indicates when the individual may not be a member of any of the groups (Ousley et al., 2006). A typicality probability of greater than 0.05 for all groups indicates that the individual likely belongs to one of them while 0.01 or below indicates it probably does not belong to any group (Ousley et al., 2006). The higher the value of the typicality probability the more likely it is to belong to one of the reference groups while a high posterior probability indicates the unknown individual most likely belongs to the reference group within which it was grouped.

Unfortunately there is little to no published research concerning the actual accuracies of testing the use of morphological skull characteristics and FORDISC to determine ancestry of unknown individuals. However, with an accuracy of almost 90% the discriminant function developed using articulated hyoids is similar in accuracy to previous metric methods of ancestry determination using postcranial elements. DiBennardo and Taylor (1983) developed three discriminant functions using 15 measurements of the femur and pelvis that correctly identified 95% of their sample. Of these three functions the first two are the most significant with the first separating the population by sex and the second separating it by ancestry. İşcan (1983) was able to correctly assess ancestry using measurements of the pelvis with an accuracy of 83% in males and 88% in females.

One of the most recent methods used to determine ancestry is that of Hefner (2007) in his statistical analysis of cranial morphological traits and their use in estimating ancestry of the skull. He used what he refers to as macromorphoscopic traits which are non-metric traits that have been given a numeric value based on the trait's prominence or morphology (Hefner, 2007). He then used a number of classification statistics methods to determine the degree of correlation between each macromorphoscopic trait and ancestry in question in an attempt to correctly classify each skull. Each of the methods that he used correctly classified each skull at least 83% of the time with some methods achieving even higher accuracy ratings (Hefner, 2007). This appears to be a promising new method of ancestry determination that can be used with relatively little experience, but it must be noted that at its highest accuracy rating, an overall accuracy of 89% each using discriminant function analysis, logistic regression, and ordinal regression analysis (Hefner, 2007), this method is basically equivalent to the discriminant function developed using articulated hyoids which classified with 88.9% accuracy. This suggests that although the use of the hyoid to estimate ancestry may be unconventional, it is a bone whose ability to contribute to an ancestry determination should be investigated even further.

Conclusion

This study has explored the relatively un-researched area of size and shape differences between hyoids of two different ancestries. Although the majority of measurements taken of articulated and disarticulated hyoids do not exhibit statistically significant size differences, those differences that do occur have the ability to shed light on why we see shape variation. This variation is most clearly seen in articulated hyoids as linear regression analysis was used to examine differences at each measurement site and principle component analysis was used to extract several factors that may contribute to the shape variation between ancestries.

In addition, the use of discriminant function analysis has demonstrated the usefulness of using the hyoid as a skeletal indicator of ancestry. In particular, the almost 90% accuracy of Function 1 suggests that discriminant functions can be used to successfully determine ancestry of an articulated hyoid. Based on this accuracy as well as the size and shape variation presented in this study, it is believed that the hyoid does have the ability to be used to distinguish between ancestries and that further research in this area can contribute more methods utilizing the hyoid to the ancestry determination process.

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CHAPTER FOUR: CONCLUSIONS

The task of building a biological profile is often daunting for physical anthropologists depending upon how many and which skeletal components are available for analysis. It is therefore imperative that methods of sex and ancestry determination be developed for as many bones in the human skeleton as possible. This study has demonstrated that size and shape differences do occur between sexes and ancestries and that, size in particular, can be used to distinguish between the two groups using metric methods. Although this study focuses on the use of size to discriminate between groups using discriminant function analysis, the shape variation that is seen using linear regression analysis and principle component analysis also presents the possibility of shape being used as the discriminating factor in similar studies in the future.

Chapter two presents clear size differences between males and females as a useful indicator of sex, and the production of five discriminant functions with accuracies of over 80% have the ability to contribute to the sex determination process. In addition, because four of these five functions can be used in the chance that a disarticulated hyoid is recovered and all five functions can be used if an articulated hyoid is recovered, the accuracy of sexing a hyoid is increased. The regression analyses performed in this chapter also present clear shape differences between articulated male and female hyoids that may be used in future studies to distinguish between sexes. Although morphological hyoid shape has been addressed in several studies (Jelisiejew et al., 1968; Papadopoulos et al., 1989; Miller et al., 1998; Lekşan et al., 2005; Shimizu et al., 2005), studying the metric shape of the bone, particularly of articulated hyoids, is an area of hyoid research that also has the ability to heighten the usefulness of the hyoid in sex determination.

Chapter three is unique due to the fact that size and shape differences of the hyoid between ancestral groups are not often approached and this study uses several statistical methods to examine them. In the analysis of size variation between African and European hyoids, although the majority of the measurements do not exhibit statistically significant differences in size, those that do provide enough variation for discriminant function analysis to distinguish between the two groups with almost 90% accuracy. Unfortunately disarticulated hyoids are not as accurately classified, but again the advantage of using multiple discriminant functions to estimate the ancestry of a disarticulated hyoid is that they can be used in conjunction with one another to increase the accuracy of the estimation. Neither morphological nor metric shape differences have been explored in previous research so that the results of the regression analyses and principle component analysis could possibly present only a sample of shape differences between the two ancestries that have the ability to be used in future research.

The overall purpose of studying bones of the human body is to learn not just about their morphology and function, but how they can be used by the physical anthropologist to identify an individual. Because this identification begins with a biological profile consisting of sex, ancestry, age, and stature it is important that a wide variety of methods are developed and used so as to increase the accuracy of the profile. This thesis has not only further explored size and shape variation of the hyoid, but has also shown that the hyoid, despite being a small, easily missed bone, has potential to aid in the determination of sex and ancestry.

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