2015

Sexual Dimorphism in the Crania in a Norwegian Sample

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SEXUAL DIMORPHISM IN THE CRANIA IN A NORWEGIAN SAMPLE

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Anthropology

in

The Department of Geography and Anthropology

by
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B.A., University of Texas at San Antonio, 2010
May 2015

Acknowledgements

First and foremost I must thank Ms. Mary Manhein, my advisor, for her endless patience and support, as well as for providing the knowledge needed to even attempt such a project. I also thank Dr. Ginesse Listi and Dr. Rebecca Saunders for completing my committee and for being understanding when things did not proceed as planned. My deep appreciations extend to the Forensic Anthropology and Computer Enhancement Services (FACES) Lab at Louisiana State University, Baton Rouge, for granting me an assistantship through which I learned so much.

This study would not have been possible without the hospitality of Dr. Per Holck and the Anthropology Department of the University of Oslo, who made me feel right at home in a windowless basement filled with human skeletons.

My deep appreciation extends to Mr. and Mrs. Hansen for letting me spend a few weeks in their guest room, for no other reason than being a friend of their daughter-in-law; my parents and my parents-in-law, for going above and beyond my expectations to help in any way they could; and my family, friends, and puppies, for not forgetting about me when my studies kept me away.

Last but certainly not least, to my husband, Joseph, for always being there for me, supporting me, and being my rock when the rest of the world seemed a bit too shaky!

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Abstract

Physical anthropologists strive to improve the accuracy of sex identification and to establish criteria of measurements within various populations. Different groups of native inhabitants show dissimilar results within cranial measurements and inaccuracies have been confirmed when comparing all populations to the common standard lineal measurements.

This research examined 24 measurements on 120 crania from Norway and used statistical analyses to determine the sexual dimorphism between male and female crania. The study established the measurements with the most sexual dimorphism. These are the measurements of bizygomatic breadth, basion-bregma, biauricular breadth, glabella-opisthocranion, and upper facial breadth. The similarity of the values of nasal breadth, maxillo-alveolar length, orbital breadth, orbital height, interorbital breadth, parietal chord, and foramen magnum length between the sexes within the sample can rule out these measurements as a way to establish the sex of an unidentified individual.

When running the measurements through the Fordisc software, it becomes clear that the values already found in the software directory are insufficient to determine the correct sex and ancestry when compared to the measurements of crania of Norwegian decent. Males often are misclassified as females and both sexes often are determined to be of incorrect ancestral group.

Chapter 1: Introduction

Sexual dimorphism refers to the difference in physical traits and characteristics between males and females. Throughout time, different intra-population tasks, ecological stress, and environmental changes have put evolutionary pressure on both male and females, resulting in variation between the sexes (Relethford and Hodges, 1985). Primary sex characteristics are those directly related to reproduction and mating, while traits not directly related are called secondary sex characteristics (Plavcan, 2001). Included in the category of primary sexual dimorphism are genital differences and differences in the pelvis. The category of secondary sexual dimorphism includes body mass and skeletal dimorphism, where the male generally is larger than the female and the canine/premolar complex, where the canine and premolar teeth of males in some species are much larger than those of females (Plavcan, 2001).

The current study investigates the degree of sexual dimorphism of the crania in a Norwegian sample and attempts to establish a baseline for the individual features and lineal measurements involved in identifying the sex of individuals of Norwegian descent. The results of this research are presented here.

Studies have shown that the divergence of the *Homo* genus' cranial morphology from that of the *Australopithecines*, as well as that of the various species within the *Homo* genus, may simply be from random genetic drift and nonbiological (i.e. cultural and visual) preferences rather than adaptive or evolutionary processes (Ackermann et al., 2004). However, it is still believed that sexual dimorphism in the crania within a genus or species is related to sexual selection and mating preference, which has resulted in physical differences between males and females (Burke and Sulikowski, 2010; Little et al., 2008; Velemínská et al. 2012). These differences include larger, heavier brow ridges, more robust crania, and more pronounced noses

and nasal cavities in males. Females have larger eyes, smaller jaws and noses, and an overall more gracile appearance (Burke and Sulikowski, 2010). Facial phenotypic characteristics of boys and girls start differentiating at the onset of puberty with the increase of testosterone in boys and estrogen in girls. The growth of the female facial features slows down in contrast to the rapid growth of the males (Velemínská et al., 2012). At puberty, the cranium is 95% of its adult size. Therefore, it has been suggested that cranial sexual dimorphism should occur before this, and that cranium/body-size ratios for boys and girls vary during puberty. It has been shown that, prior to puberty, girls have smaller crania than boys, both in relation to their own stature and compared to each other (Baughan and Demirjian, 1978). Further studies have shown that no significant changes occur to the crania after puberty to separate adult age groups. It is therefore acceptable to pool all adult specimens of the same population into groups of male and female, regardless of age (Nikita, 2012).

Sex determination is an important part of identifying remains. By determining the correct sex of an unidentified individual, one can exclude all the male possible identities and narrow down the search considerably. Several studies have been performed on this subject. Giles and Elliot (1963) were early pioneers in their research on comparing American whites and American blacks and established a discriminant function to identify 21 male-female cranial markers. Their test received an 82-89% accuracy and established the possibility of reliable ways of determining sex and ancestry (Giles and Elliot, 1963).

Many scientists recognized the importance of the research of sexual dimorphism and have since determined the usefulness of recognizing population specific traits and values (Saini et al., 2011). The genetic background determines physical qualities and characteristics and makes each population unique in its characterization as well as in sexual dimorphism (Bigoni et al.

2010). It is important to establish a base line for each distinct population and to create intra-population standards of sexual dimorphism and cranial measurements.

Population-specific craniometric variation within modern humans is believed to be a product of genetic drift and gene flow and is recognized as an important factor in determining sex using the cranium. Comparing phenotypical and craniometric inter-population similarities and differences can help trace the geographical movement and ancestral history of a population (Relethford, 2010). The first human settlements in Norway are between 9000-10,500 years old, and consisted of hunters, fishermen, and gatherers. The mountainous topography and long coastline of the country contributed to the low population and isolated communities. Throughout more modern history, emigration has been much more frequent than immigration, though some German trading groups were established within some of the larger towns sometime in the 12th century (Dupuy et al., 2006). Genetic studies show that the haplogroups of the Norwegian Y-chromosomes suggest close relationships with German ancestries from pre-historic times, as well as other Northern European countries. Centuries of secluded, self-supported economies created isolated cultural and social life (Munch, 1954) where, before the 1980s, immigrants made up less than three percent of the population (Thorvaldsen, 2011).

Chapter 2: Literature Review

Giles and Elliot (1963) began their work on using the crania to assess differences between the sexes by using nine points on the skulls of a total of 408 American whites and American blacks. By combining these nine points to form 21 measurements, they set a standard for sex determination within specific ancestral groups. They admit that when they used the established standards for American whites and American Blacks on a different ancestral group (Florida Native American) the results showed a large portion of females were misclassified as males (Giles and Elliot, 1963).

Supporting the need for an improved method of sex determination, Weiss (1972), discovered the bias toward the preference of male skeletal remains. Between ten and fifteen percent of sex determinations were wrongly classified as males when morphology alone was used to determine sex, and, therefore, skewed the archaeological record (Weiss, 1972).

As Giles and Elliot were working on establishing a discriminant function for sex determination, others were testing and challenging their findings. Kajanoja (1966) applied the discriminant function to 232 Finnish crania and achieved only an 65% accuracy. He concluded that more measurements were needed and population-specific considerations had to be included in the tests (Kajanoja, 1966).

In 1998, Steyn and Iscan noticed the lack of metric cranial criteria for South African whites. By assessing 12 standard measurements of 91 adult skulls, they established the population-specific standards for sex determination of South African whites. After carefully measuring the crania, the authors devised four regions of interest: face, vault, cranial, and mandible. By subjecting the crania to the discriminant function analysis, Steyn and Iscan

determined that bizygomatic breadth was the most dimorphic measurement, showing an accuracy rate of 80% alone. The combined measurements averaged an 86% accuracy rate (Steyn and Iscan, 1998).

Steyn and Iscan's study of South Africans of European descent was reviewed by Robinson and Bidmos in 2009 and showed equal results with no statistical significant difference from those acquired by Steyn and Iscan in 1998. Robinson and Bidmos concluded that the South African white population is homogenous enough to be considered a single group and that the equations can justifiably be used when determining the sex of an unidentified individual of European descent in South Africa (Robinson and Bidmos, 2009).

Franklin et al. examined 182 adult male and 150 adult female crania of Zulu, Swazi, Xhosa, Southern Sotho, and Tswana background. The authors used regression analyses to determine that the population variation between these groups was not significant enough to misrepresent the Indigenous Southern African group as a whole. They then proceeded to use *Morphologika*, computer software used for shape analysis, to compare the three-dimensional landmarks of the crania. When testing their discriminant classification precision, the authors concluded that the Indigenous Southern African group was noticeably sexually dimorphic and could accurately estimate the sex of the individuals 87% of the time. Franklin et al. agree that the reason they did not meet Rightmire's 90.6% accuracy in his 1971 discriminant function study of Bushmen and South African black crania, was that Rightmire only combined the Zulu and the Sotho groups to represent the South African Blacks. The higher number of local groups included by Franklin et al. might have influenced the results and could show that there is some minor cranial variation among these groups. These results support the importance of population-specific sexing criteria (Franklin et al., 2006).

Before these studies, Ricklan and Tobias (1986) had shown that the Zulu-African population showed a noticeable difference from European populations in endo-cranial sexual dimorphism. By using mustard seeds as a measurable unit of endo-cranial capacity, these authors showed that the Zulu population presented a much lower degree of endo-cranial sexual dimorphism than previously anticipated. Rather than male values being lower than expected, it became clear that the female values were elevated closer to the male standards, and that sexual dimorphism of the endo-cranial capacity in the Zulu population was much lower than expected (Ricklan and Tobias, 1986). This finding supports the claim that sexual dimorphism is population specific.

Dayal, Spocter, and Bidmos (2008) responded to Franklin et al.'s (2006) complicated software analysis of the Southern African population crania by using 22 easily reproducible measurements on 120 South African Black crania (Zulu, Tswana, Sotho, and Xhosa) to show that sexual dimorphism was visible in all measurements except orbital height. When used on these populations only, a combination of all measurements gave an average sex determination accuracy of 80-85% (Dayal et al., 2008). This conclusion was refuted by Franklin at al. in 2009 who explained that the three-dimensional data acquired by using the Microscribe was equivalent to the linear cranial measurements. These linear cranial measurements were obtained by spreading and sliding calipers and, through the use of the Pythagorean Theorem, easily can be applied to the formulas of discriminant function and used in traditional sex determination (Franklin et al., 2009).

Also using the software *Morphologika*, Green and Curnoe (2009) defined not only the degree of sexual dimorphism in the size of the cranium and its landmarks, but also shape differences. They measured the crania of 144 human adults from Southeast Asia (Myanmar,

Laos, Vietnam, Thailand, Cambodia, Philippines, Borneo, and Indonesia). This study showed how the combination of size and shape increased the sex determination accuracy from 77.1% when using shape differences only to 86.8% when adding size to the equation (Green and Curnoe, 2009).

Kimmerle et al. (2008) had different results with their studies on size and shape of American white and American black crania. The study consisted of 30 white females, 30 white males, 29 black females, and 29 black males. The size of each individual, male or female, did not affect the results of sexual dimorphism. Though males and females are shown to have different sizes, the individual traits of females and males from each group do not differ significantly from each other. This fact shows that, in relation to one's own group, the size of an individual will not matter in relation to the shape of traits or to sexual dimorphism (Kimmerle et al., 2008).

Other scholars have focused on intra-population sexual dimorphism of the skull, such as Ogawa et al. (2013), who examined 113 crania and defined nine new discriminant functions for determining sex of modern Japanese skulls. The average accuracy for sex determination with these new functions ranged from 80% to 90% in Japanese populations (Ogawa et al., 2013).

More recently, researchers have focused on individual cranial traits in an attempt to define which ones can best be utilized as a sex determinant if the cranium is in less than perfect condition. Bigoni et al. (2010) used a MicroScribe G2X contact digitizer to three-dimensionally record 82 ecto-cranial landmarks of 139 adult crania of known sex from the region of Bohemia. The results showed that the shape of the whole crania showed little to no sexual dimorphism, but the individual regions revealed several statistically significant differences. The regions of the base of the skull and the neurocranium also showed little to no difference, while the regions of

the upper face came out on top with 100% sex estimation accuracy. The shape of the nasal region, the orbital region, and the shape of the palate were the next three best discriminators with sex estimation percentage accuracy of 77%, 74%, and 70%, respectively. The authors noted that the values determined in this study must only be used to estimate the sex of crania of this population, as the application of discriminant function including values not specifically calculated for this population, can lead to significant errors (Bigoni et al., 2010).

Patel (2012) took various measurements on the hard palate of 322 Indian crania and determined that there was a noticeable size difference between males and females. He also established a normal range for the average healthy hard palate (Patel, 2012). Cantin et al. measured the piriform aperture of 90 Brazilian crania and came to similar conclusions (Cantin et al., 2009). Shearer et al. (2012) not only determined the sexual dimorphism of brow volume in African Americans, Portuguese, and California Indians, but also distinguished differences between the separate populations. Though African American and Portuguese females have similar brow ridge volume ratios, Portuguese males have much more robust brow ridges than African American males. Both male and female Late Californian Indians have larger brow-ridge volumes than the two other groups (Shearer et al., 2012). Garvin and Ruff's (2012) study using a desktop laser scanner and Geomagic Studio Software shows that European Americans in general have more robust brow ridges than African Americans. If wrong standards are used, this can often lead to the misclassification of male African Americans as females (Garvin and Ruff, 2012).

Sexual dimorphism in the foramen magnum of 211 Brazilian skulls was measured by Suazo et al. (2009) who found that, though the dimensions of the males proved to be higher than the females, the statistical tests only correctly classified the skulls 66.5% of the time. As the

foramen magnum values are higher in Central Europeans than in Middle Easterners and South Americans, it is important to use population specific standards (Suazo et al., 2009). The mastoid process has been noted by many to be one of the most sexually dimorphic features of the skull and was found to be highly sexually dimorphic in a Romanian sample of 100 individuals (Ispas et al., 2013). Apart from distinct features of the skull, various lineal measurements have been proven to indicate sexual differences and are significant in determining sexual dimorphism and the sex of unidentified remains (Zavando et al., 2009).

To try to standardize the determination of sex and ancestry of cranial remains, a software program called Fordisc was developed. This program was developed by Richard Jantz and Stephen Ousley in 1993, based on The Forensic Database, and inspired by Giles and Elliot's discriminant function research. The program is an aid to estimate the sex, ancestry, and stature of skeletal remains and uses already established information from modern and historical collections as a baseline. Fordisc is separated into several ancestral groupings and compares new input to the recognized sexual dimorphic qualities (Ousley and Jantz, 2013; Ubelaker, 1998).

Criticism of Fordisc is mainly aimed at the low population-specific information included in the software. Research done by Guymarc'h and Bruzek (2011) compares French and Thai cranial remains with the information acquired through Fordisc. The results were less than successful; the accuracy of Fordisc ranged from 52.2% to 77.8% using the different options available. The authors strongly recommend that each ethnic group and population be assessed on their own merit and the need for Fordisc to have a wider population specific search option (Guymarc'h and Bruzek, 2011).

Other studies have suggested that estimating the sex of a skull based on morphological traits has a higher accuracy than Fordisc, but that using Fordisc within the United States will still render satisfyingly accurate results. Fordisc also showed the male-biased outcomes previously discovered and that using the software in European cases cannot be recommended (Ramsthaler et al., 2007). It is also important to recognize that not all black individuals or all white individuals are equally sexually dimorphic. Black South Africans are shown to be less sexually dimorphic than African Americans, and white South Africans are shown to be less sexually dimorphic than white North Americans (L'Abbe et al., 2013). This latter study supports the significance of establishing sexually dimorphic baselines for each population.

Chapter 3: Materials and Methods

3.1 Materials

Crania Sample

The sample consists of 120 crania, 60 males and 60 females, without the mandible, from the Schreiner collection housed at the University of Oslo, Norway. The collection is named after Kristian Emil Schreiner, the Head of Department of Anatomy at the University of Oslo from 1908 to 1945 (Sellevold, 2010). Most of the remains in this collection are either discoveries of an archeological nature or excavations of cemeteries in relation to road work or other disturbances of the cemetery grounds.

The crania chosen for this research were pulled without any other biases than the criteria that follow: all were complete, with visible sutures; most were excavated from cemeteries less than two hundred years old; all were determined to be adults older than adolescence but less than 'old age.' Signs of 'old age' include edentulous crania and/or fused and invisible sutures. None of the crania were misshapen or showed any signs of malformation or pathologies. Age estimates were not available. The sex of the individuals was decided upon by medical professionals specializing in biological anthropology and osteology where burial records were not available. All chosen crania were of Norwegian descent, born in the 19th or 20th century, and have been deceased for more than 60 years.

As the crania were separated from the rest of the skeletons, there was no way of comparing the skull to the hips, in order to personally verify the sex of each individual.

Calipers

For this study, a manual sliding caliper and a manual spreading caliper were used, both within an accuracy of 1.0 mm. The calipers were provided by the Forensic Anthropology and Computer Enhancement Services (FACES) Lab at Louisiana State University, Baton Rouge.

Fordisc Software

Fordisc 3 is a statistical software program intended to help anthropologists identify ancestry and sex of an unidentified individual. This software uses discriminant function analysis to analyze the measurements of the crania. The measurements are compared to several ancestral categories and separated by ancestry.

3.2 Methods

Measurements

The author took 24 measurements on each skull. These measurements are deemed the standard within data collection of forensic material and measured using 24 selected cranial landmarks (Table 1) (Moore-Jansen et al., 1994). Figures 1-4 illustrate the measurements taken.

Measurement Precision

To minimize intra-observer error, all initial measurements taken twice and were double checked at the time of measuring, and every tenth cranium was re-measured one week after initial measurements were taken. All measurements were recorded in millimeters.

Table 1. Cranial Measurements

	Points of Measurements	Caliper Used
1	Glabella - Opisthocranion (G-OP, Maximum Cranial Length)	Spreading Calipers
2	Euryon - Euryon (EU-EU, Maximum Cranial Breadth)	Spreading Calipers
3	Zygion - Zygion (ZY-ZY, Bizygomatic Breadth)	Spreading Calipers
4	Basion - Bregma (BA-B, Cranial Height)	Spreading Calipers
5	Nasion - Basion (N-BA, Cranial Base Length)	Spreading Calipers
6	Basion - Prosthion (BA-PR, Facial Projection)	Spreading Calipers
7	Ectomalare - Ectomalare (ECM-ECM, Maxillo-Alveolar Breadth)	Spreading Calipers
8	Prosthion - Alveolon (PR-ALV, Maxillo-Alveolar Length)	Spreading Calipers
9	Auriculare - Auriculare (AU-AU, Biauricular Breadth)	Spreading Calipers
10	Nasion - Prosthion (N-PR, Upper Facial Height)	Sliding Calipers
11	Frontotemporale - Frontotemporale (FT-FT, Minimum Frontal Breadth)	Sliding Calipers
12	Frontomalare temporale - Frontomalare temporale (FMT-FMT, Upper Facial Breadth)	Sliding Calipers
13	Nasion - Nasospinale (N-NS, Nasal Height)	Sliding Calipers
14	Alare - Alare (AL-AL, Nasal Breadth)	Sliding Calipers
15	Dacryon - Ectoconchion (D-EC, Orbital Breadth)	Sliding Calipers
16	Orbital Height (OBH)	Sliding Calipers
17	Ectoconchion - Ectoconchion (ECT-ECT, Biorbital Breadth)	Sliding Calipers
18	Maxillofrontale - Maxillofrontale (MF-MF, Interorbital Breadth)	Sliding Calipers
19	Nasion - Bregma (N-B, Frontal Chord)	Sliding Calipers
20	Bregma - Lambda (B-L, Parietal Chord)	Sliding Calipers
21	Lambda - Opisthion (L-O, Occipital Chord)	Sliding Calipers
22	Basion - Opisthion (BA-O, Foramen Magnum Length)	Sliding Calipers
23	Foramen Magnum Breadth (FOB)	Sliding Calipers
24	Mastoid Length (MDH)	Sliding Calipers

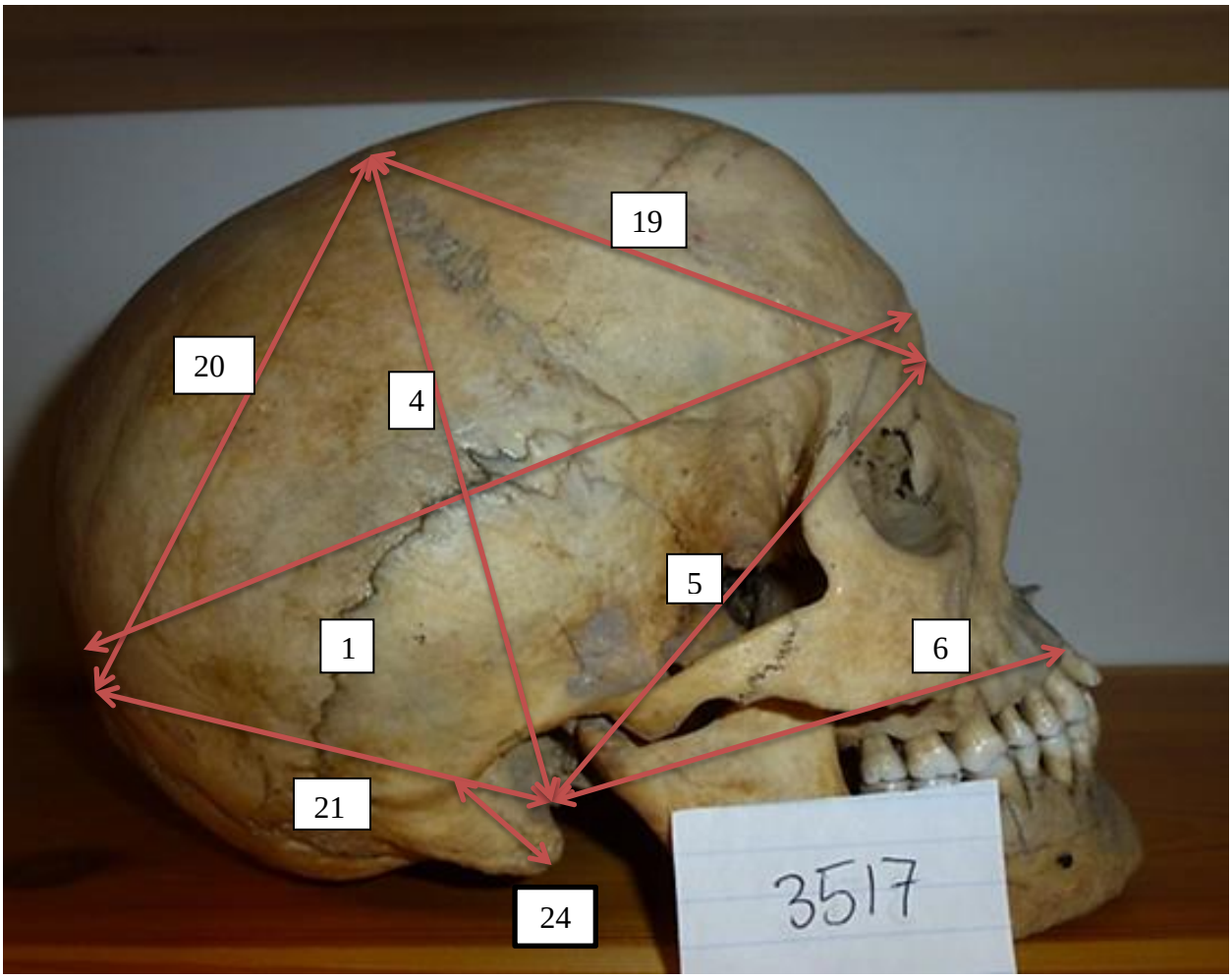


Figure 1. Cranial Measurement (Side-View) 1) Glabella-Opisthocranion (Maximum Cranial Length), 4) Basion*-Bregma (Cranial Height), 5) Basion*-Nasion (Cranial Base Length), 6) Basion*-Prosthion Length, 19) Nasion-Bregma (Frontal Chord), 20) Bregma-Lambda (Parietal Chord), 21) Lambda-Basion* (Occipital Chord), 24) Mastoid Length

*Basion is located at bottom of skull, invisible in picture

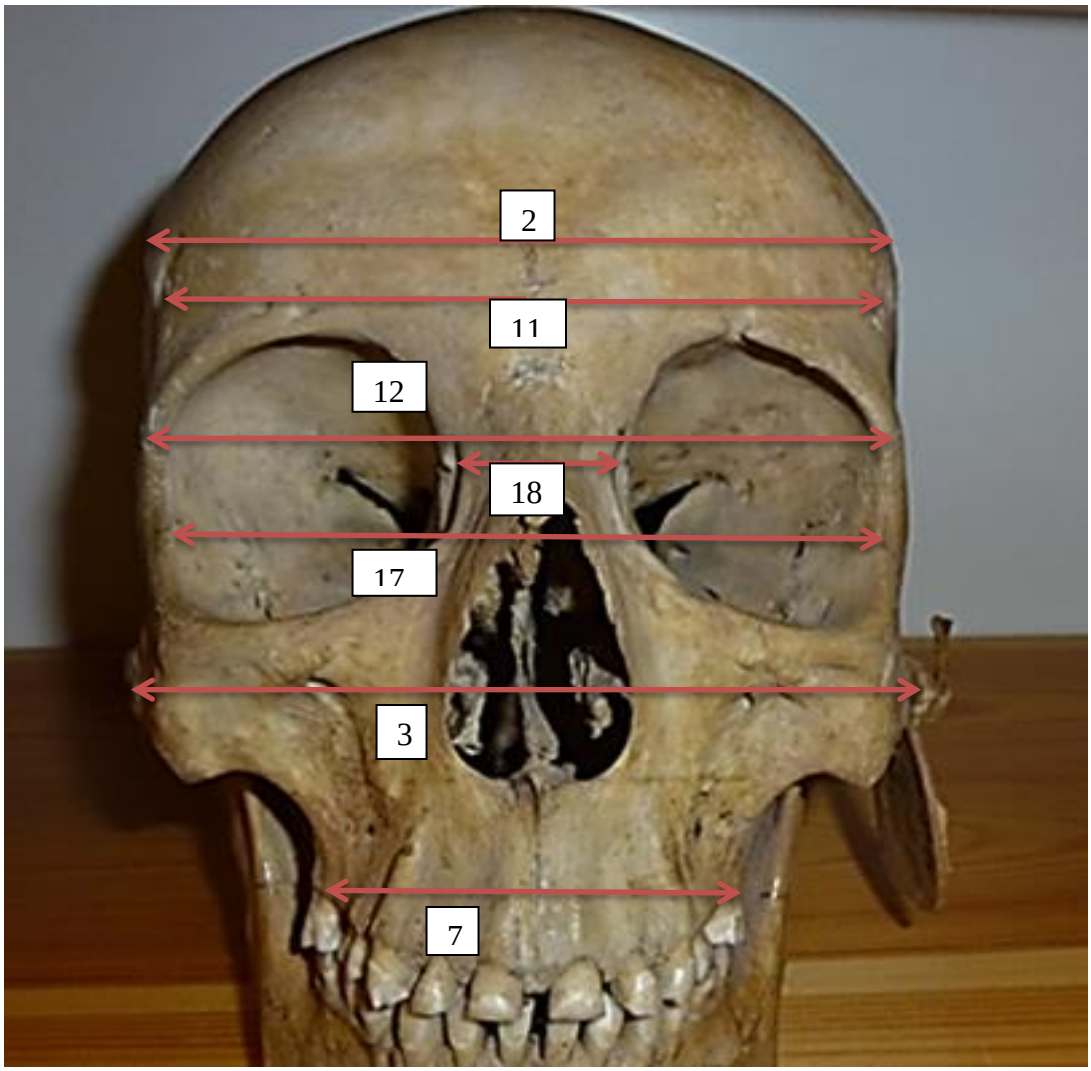


Figure 2. Cranial Measurements (Front-View**)** 2) Euryon-Euryon (Maximum Cranial Breadth), 3) Zygion-Zygion (Bizygomatic Breadth), 7) Ectomolare-Ectomolare (Maxillo-Alveolar Breadth), 11) Frontotemporale-Frontotemporale (Minimum Frontal Breadth), 12) Frontomalare temporale-Frontomalare Temporale (Upper Facial Breadth), 17) Ectoconchion-Ectoconchion (Biorbital Breadth), 18) Dacryon-Dacryon (Interorbital Breadth).

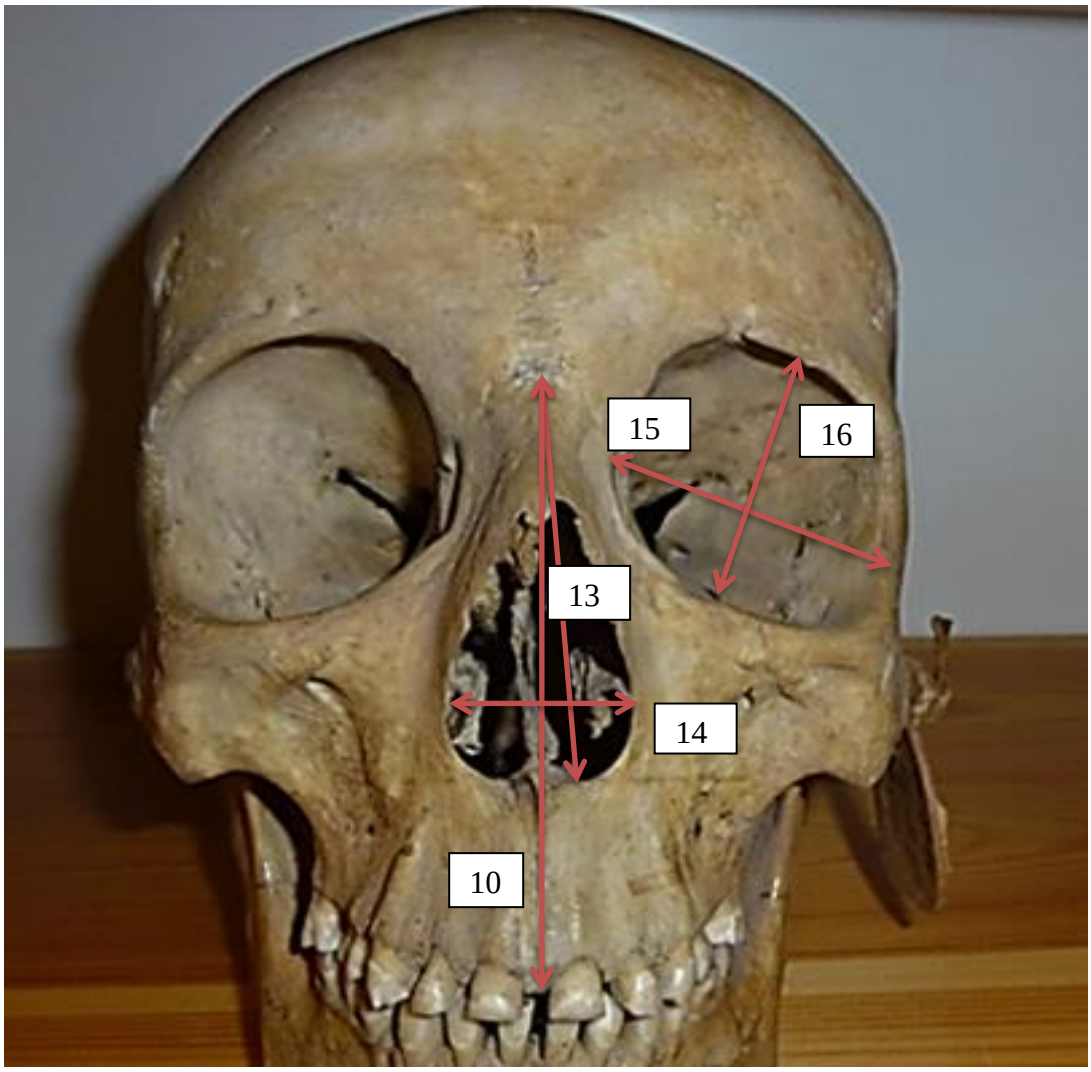
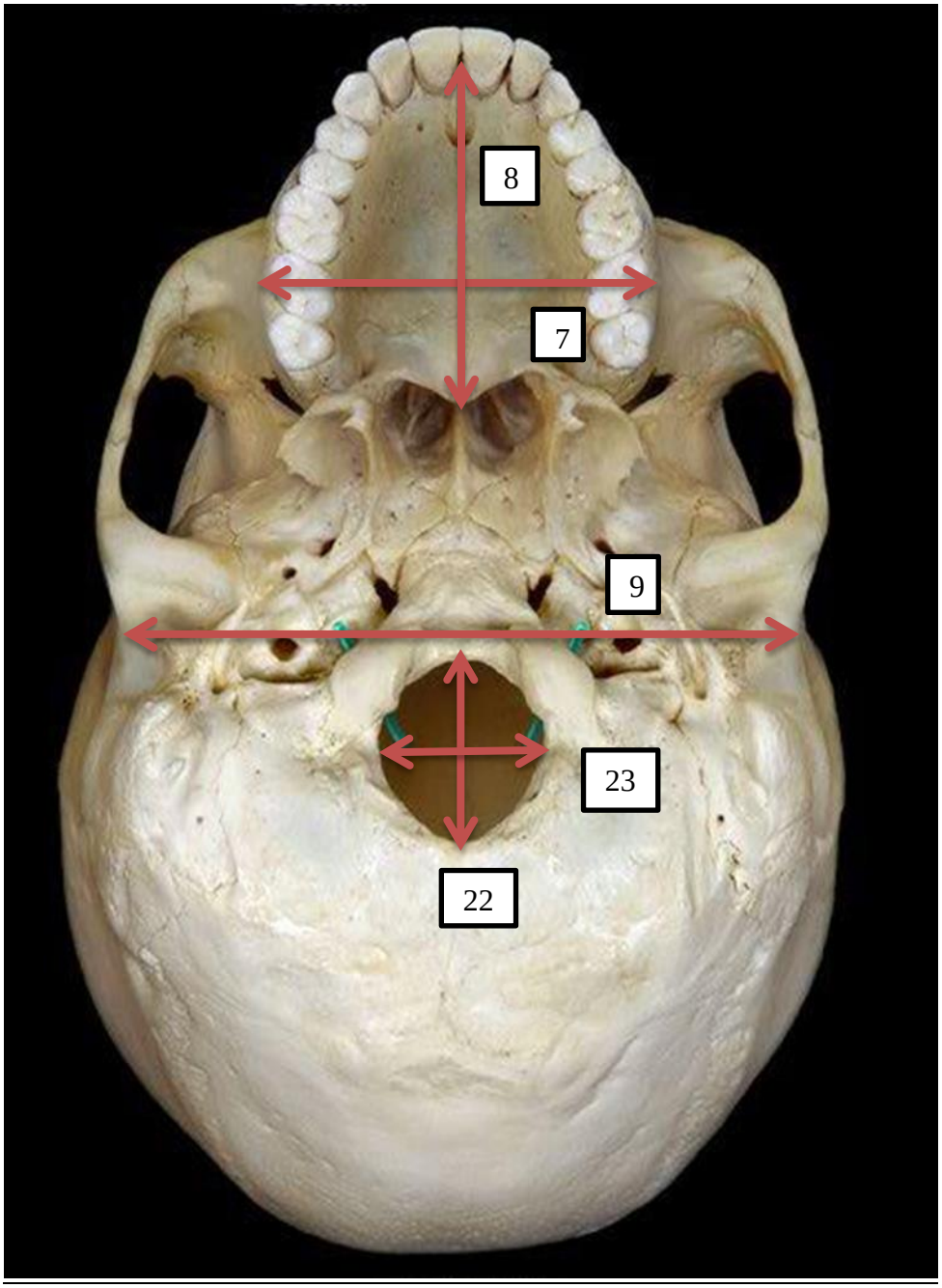


Figure 3. Facial Measurements 10) Nasion-Prosthion (Upper Facial Height), 13) Nasion-Nasospinale (Nasal Height), 14) Alare-Alare (Nasal Breadth), 15) Dacryon-Ectoconchion (Orbital Breadth), 16) Superior-Inferior Orbital Margin (Orbital Height).



(https://classconnection.s3.amazonaws.com/929/flashcards/1780929/jpg/vomer-inferior1348241683610.jpg)

Figure 4. Cranial Meaurements (Inferior View**)** 7) Ectomolare-Ectomolare (Maxillo-Alveolar Breadth), 8) Prosthion-Alveolon (Maxillo-Alveolar Length), 9) Auriculare-Auriculare (Biauricular Breadth), 22) Basion-Opisthion (Foramen Magnum Length), 23) Foramen Magnum Breadth

Statistical Analyses

The purpose of this study was first to establish a baseline for sexual dimorphism in metric data in the crania in the Norwegian population. The second goal of this study was to determine the appropriate measurements to make an accurate estimation of the sex of unidentified cranial remains of Norwegian descent. All statistical tests were run in Microsoft Excel 2010 or JMP Pro 2011.

The mean of each group of measurements was calculated and compared to the opposite sex. The statistical significance of the difference between the means was then determined.

The standard deviation of each measurement was calculated in order to recognize the variation within each group.

The confidence interval and the standard error of the mean were calculated to anticipate the boundaries of the mean of each measurement within the Norwegian population as a whole. The alpha value (α) was set at 0.05, meaning a confidence level of 95% that the true mean of the population was included within established boundaries.

The confidence interval of the mean of the population was then compared between each sex for each measurement. The overlapping intervals were discarded as sex identifying features, but are still identifying the degree of sexual dimorphism within the population.

A two-tailed t-test was then used to explore the null hypothesis that there is no difference between male and female means for each measurement. This test was also established on a level of significance of 0.05, or 95%. The degree of freedom of each measurement fell into the category of 100, and the critical value was found to be 1.984.

Fordisc Analyses

The purpose of the Fordisc analysis is mainly to determine if the program can accurately determine the sex and ancestry of sample crania. The measurements for each cranium were entered into the Fordisc program and run through six scenarios: All Basic Groups, All Howell's Groups, Narrowed Basic Groups, Narrowed Howell's Groups, White Basic Groups, and White Howell's Groups. Table 2 shows the ancestral groups included in the Basic group and the Howell's group.

Table 2. Fordisc Categories

	Basic Group:	Howell's Group:
Male:	African Americans, American Indians, American whites, Chinese, Guatemalans, Hispanics, Japanese, Vietnamese	Ainu (Hokkaido, Japan), Andaman Island (Andaman Islands), Anyang (China), Arikara (South Dakota, USA), Atayal (Taiwan), Australia (Lower Murray River), Berg (Austria), Buriat (Siberia, Russia), Bushman (South Africa), Dogon (Mali), Easter Island (Easter Island), Egypt (Gizah), Eskimo (Greenland), Guam (Guam), Hainan (China), Mokapu (Hawaii), Moriori (Chatham Islands), Norse (Oslo, Norway), North Japan (Hokkaido, Japan), Peru (Peru), Phillipines (Phillipines), Santa Cruz (California, USA), South Japan (Kyushu, Japan), Tasmania (Tasmania), Teita (Kenya), Tolai (New Britain), Zalavar (Hungary), and Zulu (South Africa)
Female:	African Americans, American Indians, American whites, Hispanics, Japanese, Vietnamese	Ainu (Hokkaido, Japan), Andaman Island (Andaman Islands), Anyang (China), Arikara (South Dakota, USA), Atayal (Taiwan), Australia (Lower Murray River), Berg (Austria), Buriat (Siberia, Russia), Bushman (South Africa), Dogon (Mali), Easter Island (Easter Island), Egypt (Gizah), Eskimo (Greenland), Guam (Guam), Hainan (China), Mokapu (Hawaii), Moriori (Chatham Islands), Norse (Oslo, Norway), North Japan (Hokkaido, Japan), Peru (Peru), Phillipines (Phillipines), Santa Cruz (California, USA), South Japan (Kyushu, Japan), Tasmania (Tasmania), Teita (Kenya), Tolai (New Britain), Zalavar (Hungary), and Zulu (South Africa)

The specific populations included in the "all," "narrow," and "white" groups are indicated in Table 3; as are the expectations for a 'correct' classification. In the "narrow" group, only ancestral groups more likely to be found in Norway were included, which is the most appropriate use of Fordisc.

Table 3. Fordisc Analyses

	Groups Included	**Groups Considered Correct**
Basic, All Groups	All Groups	White Male/Female
Howell's, All Groups	All Groups	White19/20* Male/Female, Norse Male/Female
Basic, Narrow Groups	White, Black, Hispanic	White Male/Female
Howell's, Narrow Groups	Black19/20 Male/Female, White 19/20 Male/Female, Norse Male/Female	White19/20 Male/Female, Norse Male/Female
Basic, White	White	White Male/Female
Howell's, White	White19/20 Male/Female, Norse Male/Female	White19/20 Male/Female, Norse Male/Female

***Born in the 19th or 20th century

When analyzing an unidentified individual of unknown ancestry both posterior probability and typical probability should be taken into account. The posterior probability estimates the probability that the sample belongs to each group referenced in the scenario, assuming that that sample does belong to at least one of the groups referenced. The closer the posterior probability is to 1, the more likely it is that the individual belongs to that particular group. A posterior probability above 0.9 is considered much closer to that group than any other while a posterior probability lower than 0.7 is too low to be considered reliable.

The typical probability represents how likely it is that the individual belongs to the group or groups assigned to it. It might suggest that the individual belongs to more than one group or no group referenced. A typical probability above 0.05 suggests that the individual is typical for the group assigned and likely to belong to this group. A number between 0.05 and 0.01 is considered atypical for the group assigned to it, but might still belong to this group or belong to more than one group, while a number lower than 0.01 is considered too atypical for the group assigned to it to be considered a part of this group and should be ignored.

As the samples in this study were of known ancestry, and the correct reference group was included in each scenario, the posterior probability and the typical probability were not considered in the classification of ancestral groups.

Chapter 4: Results

4.1 Statistical Analyses

Interpreting the Means

The first part of the interpretation of the statistical tests was to confirm a baseline of sexual dimorphism in the Norwegian crania. This was done by comparing the means of all the measurements with the corresponding mean of the opposite sex.

Figure 5 presents the means for each measurement for males and females and the difference is graphically presented. The male measurements are consistently somewhat greater than the females; the average male cranium in this sample is larger and more robust than the female. It is important to remember, however, that although the average male features are larger than the female, this does not mean that all male crania will measure larger or even have complementing features. There will be several females with one or more features larger than several male measurements.

The only mean that does not follow this pattern is the nasal breadth (AL-AL). As revealed in Figure 5, there is little difference in the mean of the male and female measurements.

The greatest differences in the means are at bizygomatic breadth, basion-bregma, biauricular breadth, upper face breadth, and glabella-opisthocranion line (Highlighted in peach in Table 4). These are the most sexual dimorphic landmarks on the Norwegian cranial samples. The least sexual dimorphic landmarks in the same sample are highlighted in blue in Table 4, and will be explored further in the next analyses.

Figure 5. Comparison of Means in Millimeters

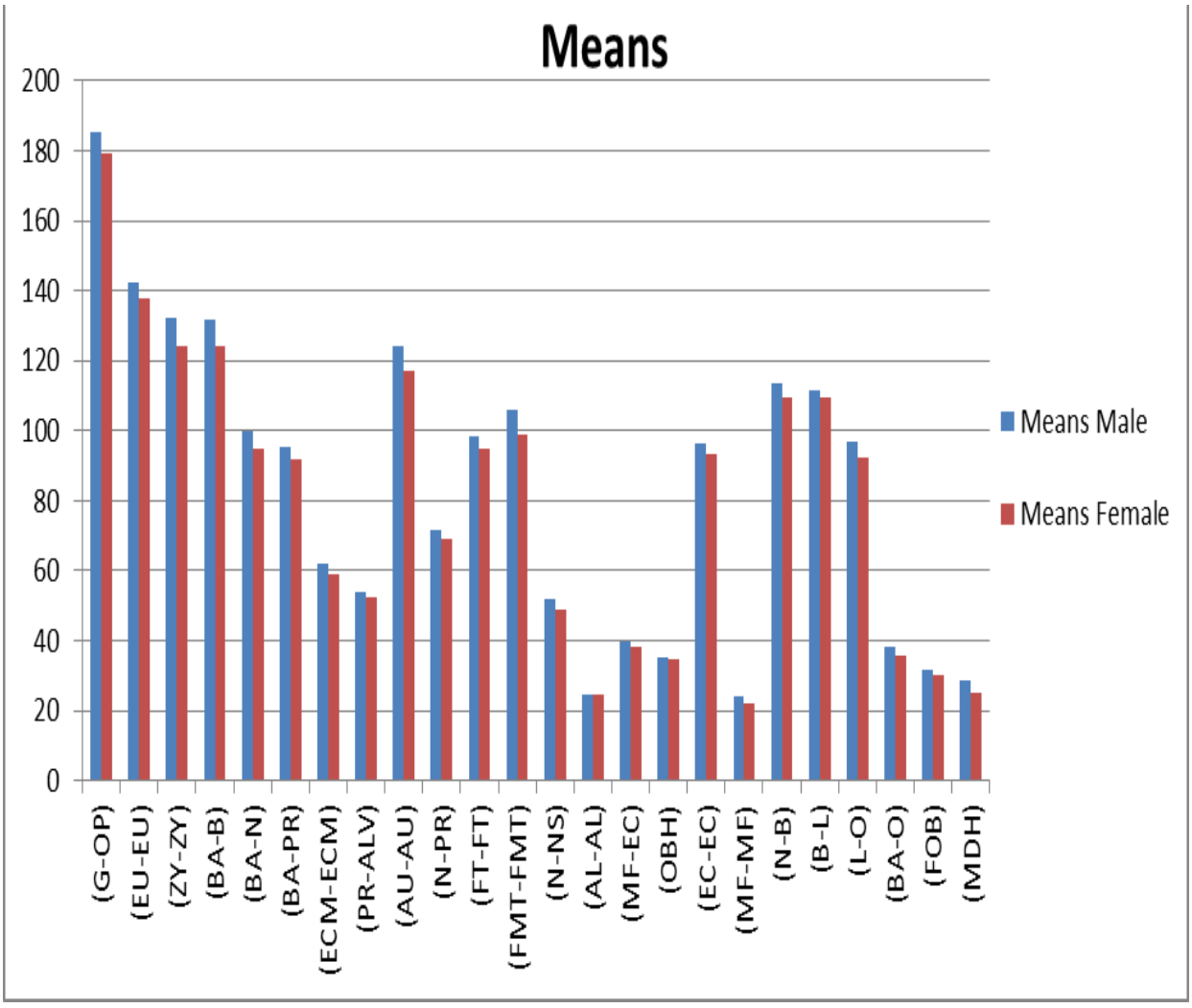


Table 4. Differences in Means

Measurements	Mean Males	Mean Females	Difference
G-OP	185.3	179.28	6.02
EU-EU	142.37	137.68	4.69
ZY-ZY (Bizygomatic Breadth)	132.09	124.14	7.95
BA-B (Basion-Bregma)	131.66	124.03	7.63
BA-N	100	94.8	5.2
BA-PR	95.52	91.6	3.92
ECM-ECM	61.83	59.17	2.66
PR-ALV	53.88	52.39	1.49
AU-AU (Biauricular Breadth)	124.07	117.02	7.05
N-PR	71.53	68.28	3.25
FT-FT	98.21	94.84	3.37
FMT-FMT	106.02	98.95	7.07
N-NS	52.03	48.85	3.18
AL-AL	24.57	24.41	0.16
MF-EC	39.67	38.44	1.23
OBH (Orbital Heigth)	35.15	34.55	0.6
EC-EC	96.21	93.15	3.06
MF-MF	23.9	22.08	1.82
N-B	113.32	109.34	3.98
B-L	111.46	109.6	1.86
L-O	96.85	92.2	4.65
BA-O	38	35.92	2.08
FOB	31.53	30	1.53
Mastoid Length	28.67	24.93	3.74

Highlighted in peach: The most sexually dimorphic measurements.
Highlighted in blue: The least sexually dimorphic measurements.

Standard Deviation

After calculating the means, the standard deviations were computed (Tables 5 and 6). The standard deviation shows us the variation around the mean and is also represented in millimeters. One standard deviation encompasses approximately 68% of the raw scores, 34% on either side of the mean. In the case of the Cranial Length (G-OP) measurements, one female standard deviation is just over five millimeters. Therefore, 68% of the crania are within five millimeters from either side of the mean, which, in this category, is just over 179 millimeters. The second standard deviation encompasses approximately 95% of the score, about 47% on either side of the mean, and the third standard deviation encompasses approximately 99% of the scores.

The standard deviations for each sex show similar spans from the mean with only a few exceptions. Of the females, the upper facial breadth (FMT-FMT), biorbital breadth (EC-EC), and interorbital breadth (MF-MF) standard deviations show a much wider distribution (Highlighted in green on Table 5). These three categories show a standard deviation of over 10 millimeters, meaning that there is a wide variation among females regarding these measurements. The male standard deviations show a similar trend where the biorbital breadth and the interorbital breadth also have a standard deviation of more than ten millimeters from the mean.

Standard Error of Mean and Confidence Interval

Also reported on Tables 5 and 6, is the standard error of the mean for each measurement. This statistic indicates how close the sample mean is to the population mean. In the case of the female cranial length, there is a 68% chance that the true Norwegian female population mean is within 0.65 millimeters of the sample mean. When calculated to show the 95% confidence level, the equivalent of two standard errors of the mean estimates that the true female population means of cranial lengths is within 1.3 millimeters of the sample mean. This statistic allows us to state with 95% confidence that the true population mean of Norwegian female cranial length is between 180.57 and 177.99 millimeters. The same category shows that the 95% confidence interval estimates the population mean of Norwegian male cranial length to be between 183.81 and 186.79 millimeters. As a result, we can compare the cranial length of an unidentified skull with the standard error of the mean and make an educated guess based on the confidence interval of the means.

Comparing the various confidence intervals in the charts, three measurements stand out: upper facial breadth (FMT-FMT), biorbital breadth (EC-EC), and interorbital breadth (MF-MF). Within these three measurements, the interval is much wider and, therefore, much less reliable in determining a confident population mean or estimating the sex of an unidentified individual. The upper facial breadth (FMT-FMT) in the male chart shows a narrower confidence interval and numbers noticeably higher than the females', though could still easily be misclassified. This category can, therefore, not be used in determining sexual dimorphism in the crania.

Table 5. Female Means, Standard Deviation, Standard Error of Means, Confidence Interval

Female	Mean	Stan Dev	Stan Err Mean	Confidence Interval
G-OP	179.28	5.09	0.65	180.57-177.99
EU-EU	137.68	4.62	0.58	138.84-136.51
ZY-ZY	124.14	4.39	0.6	125.34-122.93
BA-B	124.03	5.36	0.68	125.38-122.68
BA-N	94.8	4.57	0.58	95.96-93.65
BA-PR	91.6	4.16	0.53	92.66-90.55
ECM-ECM	59.17	3.53	0.51	60.19-58.15
PR-ALV	52.39	8.64	1.07	54.57-50.2
AU-AU	117.02	7.61	0.97	118.96-115.07
N-PR	68.28	3.99	0.51	69.29-67.26
FT-FT	94.84	3.96	0.5	95.84-93.83
FMT-FMT	98.95	13.35	1.7	102.34-95.56
N-NS	48.85	4.28	0.54	49.93-47.78
AL-AL	24.41	8.32	1.07	26.54-22.28
MF-EC	38.44	1.76	0.22	38.89-38
OBH	34.55	2.02	0.26	35.07-34.03
EC-EC	93.15	12.44	1.58	96.31-89.99
MF-MF	22.08	11.16	1.41	24.89-19.27
N-B	109.34	4.46	0.56	110.46-108.21
B-L	109.6	5.21	0.66	110.91-108.29
L-O	92.2	8.26	1.06	94.32-90.08
BA-O	35.92	2.37	0.3	36.52-35.31
FOB	30	2.56	0.33	30.66-29.34
Mastoid Length	24.93	2.99	0.39	25.71-24.15

Highlighted in green: The largest distribution within one standard deviation
Highlighted in yellow: The largest distribution within the Confidence Interval

Table 6. Male Means, Standard Deviation, Standard Error of Mean, Confidence Interval

Male	Mean	Stan Dev	Stan Err Mean	Confidence Interval
G-OP	185.3	5.88	0.75	186.79-183.81
EU-EU	142.37	5.5	0.7	143.77-140.96
ZY-ZY	132.09	5.13	0.68	133.45-130.73
BA-B	131.66	9.11	1.16	133.97-129.34
BA-N	100	3.95	0.5	101.00-99.00
BA-PR	95.52	9.27	1.19	97.89-93.14
ECM-ECM	61.83	5.71	0.88	63.61-60.05
PR-ALV	53.88	3.13	0.4	54.68-53.08
AU-AU	124.07	4.91	0.63	125.23-122.81
N-PR	71.53	5.13	0.66	72.85-70.22
FT-FT	98.21	3.99	0.51	99.23-97.20
FMT-FMT	106.02	3.91	0.5	107.01-105.02
N-NS	52.03	3.65	0.46	52.96-51.11
AL-AL	24.57	1.95	0.25	25.07-24.08
MF-EC	39.67	1.34	0.17	40.03-39.35
OBH	35.15	1.67	0.21	35.57-34.72
EC-EC	96.21	12.88	1.64	99.48-92.94
MF-MF	23.9	10.37	1.33	26.56-21.24
N-B	113.32	5.95	0.76	114.83-111.81
B-L	111.46	6.73	0.87	113.20-109.72
L-O	96.85	5.34	0.69	98.23-95.47
BA-O	38	7.22	0.93	39.85-36.15
FOB	31.53	2.49	0.32	32.17-30.89
Mastoid Length	28.67	3.35	0.44	29.55-27.80

Highlighted in green: The largest distribution within one standard deviation
Highlighted in yellow: The largest distribution within the Confidence Interval

Comparing the Confidence Interval

Table 7 compares the confidence intervals of means of both sexes and the categories that overlap are highlighted in blue. These measurements will not be useful in determining the sex of an unidentified cranium, but are still included in the determination of degree of sexual dimorphism within the population.

Table 7. Comparison of Confidence Intervals of Means

Measurements	CI Males	CI Females
G-OP	186.79-183.81	180.57-177.99
EU-EU	143.77-140.96	138.84-136.51
ZY-ZY	133.45-130.73	125.34-122.93
BA-B	133.97-129.34	125.38-122.68
BA-N	101-99	95.96-93.65
BA-PR	97.89-93.14	92.66-90.55
ECM-ECM	63.61-60.05	60.19-58.15
PR-ALV (Maxillo Alveolar Length	54.68-53.08	54.57-50.2
Biaur. Breadth	125.23-122.81	118.96-115.07
N-PR	72.85-70.22	69.29-67.26
FT-FT	99.23-97.20	95.84-93.83
FMT-FMT	107.01-105.02	102.34-95.56
N-NS	52.96-51.11	49.93-47.78
AL-AL (Nasal Breadth)	25.07-24.08	26.54-22.28
MF-EC	40.03-39.35	38.89-38
Orbital Heigth	35.57-34.72	35.07-34.03
EC-EC (Biorbital breadth)	99.48-92.94	96.31-89.99
MF-MF (Inter Orbital Breadth)	26.56-21.24	24.89-19.27
N-B	114.83-111.81	110.46-108.21
B-L (Parietal Chord)	113.20-109.72	110.91-108.29
L-O	98.23-95.47	94.32-90.08
BA-O (Foramen Magnum Length)	39.85-36.15	36.52-35.31
FOB	32.17-30.89	30.66-29.34
Mastoid Length	29.55-27.80	25.71-24.15

Highlighted in blue: Overlapping distribution

Two-tailed T-test and Null Hypothesis

The two-tailed t-test shown in Table 8 explores the null hypothesis that there is no difference between the measurements of each sex. The level of significance is 0.05, or 95%. The degree of freedom is 100 and critical value is found to be 1.984. These values are established by adding the numbers of crania in each sex group, subtracting two from this answer, and determining the nearest degree of freedom and critical value from a pre-established list without going over (Caldwell 2010). If the t-stat value is larger than the critical value, the null hypothesis is rejected and the differences between the sexes are considered statistically relevant.

This test shows us that the categories in which we failed to reject the null hypothesis are the same in which the confidence interval of means overlap between the sexes, with the exception of ectomalare-ectomalare and foramen magnum length. These categories are not significantly different, since they are not sexually dimorphic, and they should not be taken into account when trying to determine the sex of an unidentified skull.

Table 8. Two-tailed T-test

Measurements	T-stat < or > Crit. Val.	Conclusion
G-OP	5.87 > 1.98	Reject null hyp.
EU-EU	4.89 > 1.98	Reject null hyp.
ZY-ZY	8.24 > 1.98	Reject null hyp.
BA-B	5.43 > 1.98	Reject null hyp.
BA-N	6.55 > 1.98	Reject null hyp.
BA-PR	2.82 > 1.98	Reject null hyp.
ECM-ECM	2.45 > 1.98	Reject null hyp.
PR-ALV (Maxillo Alveolar Length	1.14 < 1.98	**Fail to reject**
Biaur. Breadth	5.82 > 1.98	Reject null hyp.
N-PR	3.71 > 1.98	Reject null hyp.
FT-FT	4.48 > 1.98	Reject null hyp.
FMT-FMT	3.86 > 1.98	Reject null hyp.
N-NS	4.24 > 1.98	Reject null hyp.
AL-AL (Nasal Breadth)	0.06 < 1.98	**Fail to Reject**
MF-EC	4.12 > 1.98	Reject null hyp.
Orbital Heigth	1.62 < 1.98	**Fail to Reject**
EC-EC (Biorbital breadth)	1.29 < 1.98	**Fail to Reject**
MF-MF (Inter Orbital Breadth)	0.88 < 1.98	**Fail to Reject**
N-B	3.96 < 1.98	Reject null hyp.
B-L (Parietal Chord)	1.73 < 1.98	**Fail to Reject**
L-O	3.53 > 1.98	Reject null hyp.
BA-O	2.14 > 1.98	Reject null hyp.
FOB	3.08 > 1.98	Reject null hyp.
Mastoid Length	6.09 > 1.98	Reject null hyp.

4.2 Fordisc Analyses

The purpose of the Fordisc analyses is to establish the accuracy of the results when using the dimensions of a population whose measurements were not extensive enough or included in the software. The analyses in this part of the study have been divided into three categories: all groups, narrow groups, and white groups. Each category consists of two parts using populations from the Basic and Howell's groups, creating six scenarios in all.

Looking at Table 9, the comparison of all groups, it becomes clear that there are many difficulties in estimating the correct sex and ancestry of Norwegian populations using Fordisc. Sex determination of the male crania was inaccurate 53.4% and 35% of the time in Basic- and Howell's all groups respectively, and categorized as other than white in 86.7% and 58.4% of the time. The female sex classification was much more accurate with correct percentages of 93.3% and 88.3%, though the female ancestry classification was still low with correct percentages of 31.6% and 45% (Table 9).

Table 9. Percentage of Correct Results in All Groups

	Total sample	All Groups, Basic	All Groups, Howell
Male Sex	60	28 (46.6%)	39 (65%)
Male Ancestry	60	8 (13.3%)	25 (41.6%)
Female Sex	60	56 (93.3%)	53 (88.3%)
Female Ancestry	60	19 (31.6%)	27 (45%)

In the second category, the cranial measurements are compared to the narrowed groups, with the results showed in Table 10. The Basic narrow group consists of white, black, and Hispanic ancestry, and the Howell's narrow group contains white and black from both 19th and 29th century, and Norse ancestry. The accuracy of these groups, when compared to the cranial measurements, has increased in relation to the numbers in Table 9. The correct sex estimations of

the male crania have improved to 71.6% in the Basic grouping, while it stayed the same at 65% in Howell's grouping. The correct ancestry estimation for males has increased from 13.3% to 38.3% in the Basic grouping, and from 41.6% to 86.6% in the Howell's grouping. The female sex estimation is still much stronger than the males' at a solid 90% in both groupings, with 41.6% and 83.3% accurate ancestry estimation (Table 10).

Table 10. Percentage of Correct Results in Narrow Groups (*White, Black, Hispanic) (**White19, White20, Black19, Black20, Norse)

	Total Sample	Narrow Groups*, Basic	Narrow Groups**, Howell
Male Sex	60	43 (71.6%)	39 (65%)
Male Ancestry	60	23 (38.3%)	52 (86.6%)
Female Sex	60	54 (90%)	54 (90%)
Female Ancestry	60	25 (41.6%)	50 (83.3%)

For the third and last category of estimation, the measurements are exclusively compared to white categories so only the correct sex estimations have been recorded. The males are still inaccurately classified as females 43.4% and 35% percent of the times in the Basic- and Howell's white groupings. The correct female estimation is much higher with numbers of 83.3% and 91.6% (Table 11).

Table 11. Percentage of Correct Results in White groups

	Total Sample	Whites, Basic	Whites, Howell
Male Sex	60	34 (56.6%)	39 (65%)
Female Sex	60	50 (83.3%)	55 (91.6%)

Chapter 5: Discussion and Conclusion

The purpose of these measurements and the analyses that followed was to first investigate the relationship between male and female crania and the differences in cranial measurements as they relate to sexual dimorphism. These measurements were then used to suggest the cranial criteria for determining the sex of an unknown individual within the Norwegian population. Secondly, this study explored the confidence interval of the population mean as a whole.

At first, the author calculated the means of the sample and determined that males consistently have larger, more robust measurements than females. The author then determined the standard deviation of the sample using these numbers to calculate the standard error of sample mean and the expected population mean of each measurement within an accepted limit of confidence.

From comparing the sample means, this study identified the measurements with the most sexual dimorphism. These are the measurements of bizygomatic breadth (ZY-ZY), basion-bregma (BA-B), biauricular breadth (AU-AU), upper facial breadth (N-PR), and glabella-opisthocranion (G-OP). The similarity of nasal breadth (AL-AL), maxillo-alveolar length (PR-ALV), orbital breadth (MF-EC), orbital height (OBH), interorbital breadth (MF-MF), parietal chord (B-L), and foramen magnum breadth (FOB) between the sexes can rule out these measurements as a way to establish the sex of an unidentified individual.

Through the established confidence intervals of population means, this study also recognized the wide variation of female upper facial breadths (FMT-FMT), biorbital breadths (EC-EC), and interorbital breadths (MF-MF), as well as the male biorbital breadths (EC-EC), and interorbital breadths (MF-MF), and determined that these distributions were too wide to confidently use for estimation of an unknown individual's sex.

The overlapping ranges in estimated population means within the confidence intervals also rule out maxillo-alveolar breadth (ECM-ECM), maxillo-alveolar length (PR-ALV), orbital height (OBH), parietal chord (B-L), and foramen magnum length (BA-O), as well as nasal breadth (AL-AL), orbital height(OBH), biorbital breadth (EC-EC), and interorbital breadth (MF-MF), which have already been established as unsatisfactory in identifying the sex of crania of Norwegian decent.

Further tests were used to investigate the statistical significance of the differences between males and females. Here, this study recognizes that all differences were large enough to be statistically significant except for the already discerned maxillo-alveolar length (PR-ALV), orbital height (OBH), foramen magnum length (BA-O), nasal breadth (AL-AL), orbital height (OBH), biorbital breadth (EC-EC), interorbital breadth (MF-MF), and parietal chord (B-L). These tests confirm these values to be unusable as a way to estimate the sex of a skull, but are still important factors in identifying the population variation.

Reviewing the Fordisc results, it becomes clear that the values already found in the software directory are insufficient in determining the correct sex and ancestry when compared to the measurements of crania of Norwegian decent. Males are often misclassified as females and both sexes are often determined to be of incorrect ancestry. The only high percentages of accuracy were the correct classifications of female skulls which ranged from 83.3% to 93.3%, which deems it a higher likelihood that a female individual will be classified correctly. Though these numbers are high, knowing the uncertainty of correct classification of the males, it is difficult to state with a high likelihood that an unknown individual categorized as female is not actually a male, and male individuals could easily be wrongly classified.

Other studies that could prove to be useful and should be performed are the variation between the historical Norwegian upper class and the peasant class and the variation between Norwegian historical samples and modern samples. Norwegian peasant class and upper class were widely separated both in cultural life and in geographical locations with almost no interaction until the steamship lines and railways were introduced in the mid 1800's. This caused big changes in the lifestyle and culture of the Norwegian people of both classes (Munch, 1954). These studies would be much too extensive to be performed in relation with this current study.

There is evidently a strong need for population-specific standards for the inhabitants of Norwegian descent, and in order to acquire them, more research is needed.

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Vita

Tonje Bakke Noack was born and raised in Kristiansand, Norway, where she lived with her parents, younger brother, and younger sister. In 2005, at the age of twenty, Noack moved to Santa Monica, CA, to explore a college degree while experiencing the great world outside of Norway. Noack moved to San Antonio, TX, in 2007, where she attended The University of Texas at San Antonio, from where she earned a Bachelor of Arts degree in Anthropology in 2010.

In 2012, Noack moved to Baton Rouge, LA, to pursue a Master of Arts degree in Anthropology, focusing on forensic anthropology. Here she was granted an assistantship by the Forensic Anthropology and Computer Enhancement Services (FACES) Lab.

Noack now lives in Coldspring, TX, with her husband, her one-year-old son, and two dogs. She plans to pursue a career in forensic anthropology.