SEX ESTIMATION UTILIZING DIMENSIONS FROM THE OCCIPITAL BONE, ATLAS, AND AXIS

By

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ABSTRACT

Various bones can be used to estimate sex of skeletal remains of a human. Because of distinct sexual dimorphism, bones of the pelvis and skull are preferred; however, these bones are often unavailable or damaged, and researchers are forced to use other bones to estimate sex. My study focuses on the diagnostic utility of the occipital, atlas, and axis to estimate sex. Previous studies have indicated that these bones can estimate sex with 69 – 90% accuracy for the base of the cranium, 60 – 89% accuracy from dimensions of the atlas, and 82 – 90% accuracy from dimensions from the axis. To explore whether the accuracy of these bones for estimating sex could be increased, I measured 30 discrete features of these bones, including 24 previously used and six new measurements, on 83 modern white individuals from the William M. Bass Skeletal Collection at the University of Tennessee, Knoxville, USA. I used FORDISC 3.1 and R 3.3.2 for my analyses. I was able to estimate sex with an accuracy of 77% for the occipital, 76.9 – 80.0% for the atlas, 89.2% for the axis, and 87.1 – 88.6% combined.

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CHAPTER I: INTRODUCTION

Brief Biological Anthropology Introduction

Anthropology is the analysis of human cultures, archaeology, languages, and biology (Ember, Ember, and Peregrine 2011). Human skeletal analysis, an aspect of biological anthropology, focuses on the anatomical aspects of humans from archaeological and forensic contexts (Ember, Ember, and Peregrine 2011). Bioarchaeologists and forensic anthropologists use ancestral origin, age at death, sex, stature and physical pathologies of skeletonized remains to develop a biological profile of an individual (Trammell and Kroman 2013). An essential component of this profile is the estimation of sex, which relies on the detection of structural differences in skeletal components between males and females (White and Folkens 2005).

Male and Female Biological Differences that Impact Bone Morphology

As a living tissue, the skeleton is specialized for various functions during human life (White and Folkens 2005, Saladin 2012). The skeleton retains physical traces, usually seen in size and morphological appearances, of these functions after death (White and Folkens 2005). Physical differences between males and females in these features are known as sexual dimorphism (White and Folkens 2005, Saladin 2012). Hormones influence bone growth by controlling when osteoblasts deposit bone, and spikes in testosterone and estrogen during puberty impact the physical make-up of the human skeleton (Saladin 2012). For instance, males achieve a taller height than females because of higher levels of testosterone that maintain bone growth longer in males; whereas, estrogen produces a strong response in bone growth in females that causes them to reach their full stature before males (Saladin 2012). Sexually dimorphic traits of the skeleton

generally are not visible until after puberty; consequently, sex estimation of skeletal remains is restricted to adults (Moore 2013).

Metric and non-metric techniques are used to create a profile of various sexually dimorphic skeletal elements (Buikstra and Ubelaker 1994, White and Folkens 2005). Because of the function during pregnancy and birth, the female pelvis is distinct from the male pelvis (White and Folkens 2005). For example, the pelvis of females generally is broader and wider than that of males, which by comparison is sharper, and more curved (White and Folkens 2005). Morphological analyses of the pelvis provide the most reliable sex estimation; however, those of the skull also provide reliable estimates of sex (Bass 2005, White and Folkens 2005). Sites where muscles attach to the skull are generally smaller in females than in males; consequently, cranial structures of males typically are rougher, and larger than those of females (Bass 2005, White and Folkens 2005). Because of observable and measurable differences in the pelvis and skull, these two functional units are frequently used by anthropologists and forensic scientists to estimate sex (Bass 2005, White and Folkens 2005).

Standards in Human Osteology Analyses and New, Non-Standardized Techniques

Standardized and conventional analyses include both metric and qualitative morphological analyses (Buikstra and Ubelaker 1994, Bass 2005, White and Folkens 2005). A program known as FORDISC 3.1 (Jantz and Ousley 2005, The University of Tennessee, Knoxville, Tennessee, USA) allows for relatively rapid analyses of metric data of the skull and other standardized postcranial elements.

Completely intact skeletons are seldom recovered in either archaeological excavations or forensic scenes; consequently, many human profiles are constructed from

fragmentary remains (Holland 1986 a, Marino 1995, Wescott 2000, and Papaioannou et al. 2012). The most sexually dimorphic elements of the skull and pelvis often are either missing or in poor condition (Papaioannou et al. 2012). Consequently, other parts of the skeleton not usually considered for sex estimation have to be examined if sex is to be estimated. The utility and sex estimation accuracy has been studied for other bones and features, such as the scapula, tibia, femur circumference, sternum, cervical vertebrae, thoracic vertebrae, lumbar vertebrae, and the foramen magnum (Black 1978, Iscan and Miller-Shaivitz 1984, Taylor and Twomey 1984, Holland 1986 a, Marino 1995, Wescott 2000, Lim and Wong 2004, Tatarek 2005, Gapert et al. 2009, Marlow and Pastor 2011, Babu et al. 2012, Bongiovanni and Spradley 2012, Hou et al. 2012, Wilke et al. 2012, Berthard and Seet 2013, Swenson 2013, Amores et al 2014, Gama et al. 2014). I examined the accuracy of the base of the cranium (occipital bone) and the upper vertebral column (atlas and axis) to estimate sex in modern white humans.

The Osteological Functions of the Occipital Bone, Atlas, and Axis

The vertebral column not only protects the spinal cord through its unique structure but also allows for muscle and ligament attachment (Steele and Bramblett 1988, Saladin 2012, Gray 2013). Ligaments permit nodding of the head by connecting the occipital bone to the atlas and the axis (Gray 2013). The occipital bone, atlas, and axis form a functional unit that allows for support and movement of the cranium (Steele and Bramblett 1988, Saladin 2012, Gray 2013). The base of the cranium rests on the cervical spine through articulation between the superior articular facets of the first cervical vertebra (atlas) and the occipital condyles of the occipital bone (Steele and Bramblett 1988, White and Folkens 2005, Gray 2013). The second cervical vertebra (axis)

articulates with first cervical vertebra at the superior facets of the axis and inferior facets of the atlas and the odontoid process of the axis to the fovea of the atlas (Steele and Bramblett 1988, White and Folkens 2005, Gray 2013). The articulation of the atlas and the axis enables the human head to turn left and right (Steele and Bramblett 1988, Gray 2013). Intervertebral (IV) disks develop between most consecutive vertebra and provide a cushion to absorb shock (Gray 2013); however, IV disks do not develop between either the occipital bone and the atlas, or the atlas and axis (Saladin 2012).

Previous Sex Estimation Studies of the Occipital Bone, Atlas, and Axis

The base of the cranium and the first two cervical vertebrae portray physical differences between males and females (Holland 1986 a, Marino 1995, Wescott 2000, Gapert et al. 2009, Marlow and Pastor 2011, Babu et al. 2012, Berthard and Seet 2013, Swenson 2013, Gama et al. 2014). Holland (1986 a) found that metric analysis of the foramen magnum and the occipital condyles can be used to distinguish between males and females. He examined the skeletal remains from the Robert J. Terry Collection, which contained individuals of known sex from the late 1800s and early 1900s (Iscan 1990), and found that the occipital condyles and foramen magnum of females generally were smaller than those of males (Holland 1986 a). He reported an accuracy in sex estimation of 71 – 90% with a separate control test of 70 – 85% accuracy (Holland 1986 a).

The first two cervical vertebrae also have been used to estimate sex of skeletal remains (Marino 1995, Wescott 2000, Marlow and Pastor 2011, Berthard and Seet 2013, Swenson 2013, Gama et al. 2014). Marino (1995) examined the usefulness of the atlas to estimate sex. He analyzed the atlas of skeletal remains from the Robert J. Terry

Collection, the Hamann-Todd Skeletal Collection, and an archaeological sample from site 23PM5 (Marino 1995). Marino estimated sex with an accuracy of 60 – 77% (Hamann – Todd), 75 – 85% (Terry), and 70 – 85% (23PM5) (Marino 1995). The sex of the individuals from site 23PM5 (70 – 85% sex estimation accuracy) was originally evaluated with other sex estimation techniques; thus, Marino's (1995) results are thereby susceptible to error. Wescott (2000) also studied the Robert J. Terry and the Hamann – Todd collections, but he examined the suitability of the axis, rather than the atlas, as an estimator of sex. He found that the axis is a good estimator of sex with an accuracy of 83% (Wescott 2000).

Researchers continue to revisit Holland (1986 a), Marino (1995), and Wescott's (2000) studies to further test their application on different populations (Gapert et al. 2009, Marlow and Pastor 2011, Babu et al. 2012, Berthard and Seet 2013, Swenson 2013, Gama et al. 2014). Gapert et al. (2009) estimated sex with an accuracy of approximately 69 – 77% utilizing the occipital condyles from a documented sample located at St. Bride's Church in London circa 18th and 19th century. Swenson (2013) concentrated on Marino's measurements to estimate ancestry and sex from skeletal samples at the William M. Bass Skeletal Collection, the Maxwell Museum at the University of New Mexico, and Arizona's Medical Examiner's Office in Pima County. She estimated sex with an accuracy of approximately 76 – 89% (Swenson 2013). Subsequent to Wescott (2000), other investigators have attempted to validate the reliability of measurements from the axis as an estimator of sex (Marlow and Pastor 2011, Berthard and Seet 2013, and Gama et al. 2014). Marlow and Pastor (2011) studied the British Natural History Museum's Spitalfield Collection (a collection that contains more than 300 individuals

with known sex) and estimated sex with an accuracy of approximately 83% (Cox 1996, Marlow and Pastor 2011); whereas, Berthard and Seet (2013) focused on samples from the William M. Bass Skeletal Collection and the Hamilton County Forensic Center and estimated sex with an accuracy of approximately 82 – 87%. Gama et al. (2014) used Portuguese individuals from the Identified Skeletal Collection from the 21st Century at the University of Coimbra and estimated sex with an accuracy of approximately 87% (control sample) to 90% (original sample).

Individual and Ancestral Variation

Although sexual dimorphism leaves a metric and nonmetric presence on human bones, the origin of ancestry causes variation in the morphology of bones. Variation in skeletal structure exists among individuals and populations (White and Folkens 2005). Individual variation pertains to the unique combination of genes a person possesses in their genome and the impact of nutrition, stress, and environment on skeletal growth (White and Folkens 2005, DiGangi and Hefner 2013). Population variation describes the set of genes or traits that members of a group share from common ancestry and geographic location (White and Folkens 2005, DiGangi and Hefner 2013). Another type of variation is seen when changes in the physical appearance of the skeleton occur over time (McKeown and Schmidt 2013). This difference is known as secular change which can be observed when comparing populations from different times periods, such as skeletal remains from the Victorian period to those from modern individuals (McKeown and Schmidt 2013). These variations can affect metric analyses of sex estimation (Holland 1986 a, Marino 1995, Wescott 2000, Marlow and Pastor 2011, Bethard and Seet 2013, Swenson 2013, Gama et al. 2014).

Differences in skeletal features associated with ancestry can be evaluated in anthropological studies, which makes ancestry a key component of a biological profile (Holland 1986 b, Marino 1997, White and Folkens 2005). Because variation in bone morphology is associated with ancestry, a researcher must carefully select his or her samples to avoid lowered accuracy errors caused by measurements taken from multiple populations. Because of ancestral bias, I examined skeletal remains from only one ancestral population in this study.

My Project's Focus

In prior studies, researchers analyzed the occipital bone, atlas, and axis in isolation from different populations to predict sex (Holland 1986 a, Marino 1995, Wescott 2000, Gapert et al. 2009, Marlow and Pastor 2011, Berthard and Seet 2013, Swenson 2013, Gama et al. 2014). In this project, I propose to further validate the reliability of the occipital bone and first two cervical vertebrae as reliable estimators of sex by analyzing measurements from the occipital bone (Holland 1986 a), atlas (Marino 1995), and axis (Wescott 2000). I also intend to see if combining measurements from all three of these bones will increase the accuracy rates from previous studies (Holland 1986 a, Marino 1995, Wescott 2000, Gapert et al. 2009, Marlow and Pastor 2011, Berthard and Seet 2013, Swenson 2013, Gama et al. 2014).

CHAPTER II: METHODS

Research Sample

I studied the skeletal remains of 83 modern individuals from the William M. Bass Skeletal Collection at the University of Tennessee that were classified as white (Table 1). The female age range for this sample was 32 – 97 years (Mean ± *SD* = 64.67 ± 13.76) and the male age range was 33 – 101 years (Mean ± *SD* = 63.08 ± 17.89) (Table 1). The overall age range for this sample was 32 – 101 years of age (Mean ± *SD* = 63.90 ± 15.80) (Table 1). The ages of two individuals were unknown. Both of these individuals were included in my study to see if sex could still be estimated correctly.

Bones and Their Features Analyzed

I measured 30 dimensions on the occipital bone, atlas, and axis (Holland 1986 a, Marino 1995, Wescott 2000; Table 2). Although Holland (1986 a) described nine measurements and Wescott (2000) used 10, I only utilized seven from Holland (1986 a) and eight from Wescott (2000); this resulted in only 24 measurements used from previous studies (Holland 1986 a, Marino 1995, and Wescott 2000). In addition to these dimensions, I developed six new measurements for this study, totaling 30 measurements together. To practice taking measurements, I analyzed the Skeletal Comparative Collection located in the Middle Tennessee State University Laboratory of Anthropology.

It is important to note that Holland (1986 a), utilized the foramen magnum length (LFM) and width (WFM) measurements from another source, and I am relying on his interpretation of these measurements. Either the left or right bone of paired, bilateral skeletal elements can be used in human osteological studies; however, conventionally, the left bone is used unless unmeasurable (Buikstra and Ubelaker 1994). I measured both

left and right sides of bilateral elements when possible. Marino's "maximum length of the vertebral foramen" measurement for the atlas is abbreviated "LVF," which is the same abbreviation Wescott used for his "length of vertebral foramen" for the axis (Marino 1995, Wescott 2000). To avoid confusion, I added "C1" to refer to the atlas and "C2" to designate the axis and this made the new abbreviations for these measurements to be "LVFC1" and "LVFC2" respectfully (Table 2). I also added a capital "R" or "L" to designate right or left sides respectively for each bilateral measurement to avoid confusion during analyses (Table 2).

I analyzed metric data using the general statistics and discriminant analysis with FORDISC 3.1 and R 3.3.2 (The R Foundation 2016, The University of Auckland, New Zealand). Although the utility of the FORDISC 3.1 program has been questioned (Fried et al. 2005, Aronsen and Ellis 2009, Elliott and Collard 2009), previous issues with FORDISC 3.1 were caused presumably by inappropriate application (Jantz and Ousley 2012). I used the FORDISC 3.1 program in my analyses despite these concerns, but did limit my analyses to skeletal remains from one ancestry. Also, to further verify the applicability of FORDISC 3.1 to sex estimation, I used R 3.3.2, another statistical program, for discriminant analyses. I also used R 3.3.2 to assess multivariate normality, calculate general statistics, measurement replicability, bilateral differences, and construct graphs. The multivariate Shapiro normality tests (Jarek 2012) showed that my data were nonparametric ($\alpha = 0.05$); consequently, I used the Wilcoxon test for paired data in R 3.3.2.

Sample Size and Data Formatting

I recorded measurements to the nearest 0.00 mm using Mitutoyo digital sliding calipers. I recorded measurements in hard copy handouts and then entered them into Excel 2013 spreadsheets (Microsoft Office Excel, United States 2013). I then converted them to a comma delimited format for analysis in R 3.3.2, or a dbase format through White Town conversion program (White Town, Slovakia 2016) for use in FORDISC 3.1. When I conducted analyses in FORDISC 3.1 and R 3.3.2, I checked sample sizes to make certain that the number of measurements in each analysis were the standard 1 / 3 of the sample size practiced by Richard Jantz and Stephen Ousley, the creators of FORDISC 3.1 (Ousley and Jantz 2012). It is important to note that this sample size standard was from another source and I am relying on these researchers' interpretation (Ousley and Jantz 2012).

I excluded bones that looked irregular, possibly because of pathologies, in the statistical analyses. Also, I could not take some measurements because of brittleness, extreme porosity, and bone fusions. I examined only those individual skeletons reported to have the occipital bone, atlas, and axis; however, the cranium was occasionally missing from the collection because it was used for other studies or academic lessons. Also, for FORDISC 3.1 to run analyses properly, I had to eliminate any individual skeleton missing one of the measurements. Consequently, my sample size varied based on which measurement (Table 5) or measurement combination was being analyzed (Table 6). When all three bones were analyzed together, the sample size had to be lowered to 35 individuals because of the above stated 1 / 3 of the sample size limitations (Ousley and Jantz 2012; Table 6). The sample size increased to 70 individuals when the

analyses were limited to the selected measurements (four to five) from the combined FORDISC 3.1 discriminant analyses (Table 6).

R 3.3.2 Measurement Repeatability and Bilateral Comparisons

A crucial element of metric analyses is that the measurements are reliable and can be used by multiple researchers. To assess repeatability of measurements, I remeasured three individuals (one male and two females). I selected the three individuals because they were either the first or the fourth entry I recorded in my data collection sheets. Because of time and financial constraints, I could not analyze more than three individuals for the replicability test. I used the paired Wilcoxon test to analyze measurement replicability in R 3.3.2 ($\alpha = 0.05$; Table 3). To determine if differences existed between measurements from the left and right bones of bilateral elements, I also used paired Wilcoxon tests in R 3.3.2 (Table 4).

FORDISC 3.1 Individual Measurement Discriminant Analyses

I ran discriminant function analyses in FORDISC 3.1 to evaluate the potential of the occipital bone, atlas, and axis to estimate sex. Discriminant analysis works by evaluating how efficiently specified variables, in this case measurements, estimate membership in a specific group (Ousley and Jantz 2012). My discriminant analyses were cross validated by the FORDISC 3.1 program by removing each individual from the sample when their sex was estimated (Ousley and Jantz 2012). I evaluated each measurement individually in FORDISC 3.1 to determine the sex estimation potential of each measurement.

FORDISC 3.1 Measurement Combination Discriminant Analyses

I evaluated measurements in groups based on their bone location (occipital, atlas, or axis) or if they were new measurements by using a stepwise function in FORDISC 3.1 with the Forward Wilks method (Ousley and Jantz 2012). This stepwise procedure works by selecting which measurements contribute to the estimation through the step by step addition of a single measurement based on the Wilks' lambda statistic, and if a measurement does not increase the estimation, it is removed (Ousley and Jantz 2012). My measurement combination analyses were also cross validated by the FORDISC 3.1 program (Ousley and Jantz 2012). To evaluate if a combination of measurements from more than one of the three bones would produce a higher sex estimation accuracy potential, I performed a stepwise discriminant function analysis in FORDISC 3.1 that included all 30 measurements. My sample size for this combined analysis from all three bones was reduced to 35 individuals (16 females and 19 males). I limited the total number of measurements in this analysis to five; this was done to follow the rule that the sample was at least three times as large as the number of measurements utilized (Ousley and Jantz 2012).

After this analysis was performed, I performed another discriminant analysis (non-stepwise) that looked at only the five selected measurements (XSL, LFM, SFSL, LIFL, and XDH) from the previous analysis; this increased the sample size to 70 (Table 6). I then ran a stepwise discriminant analysis in FORDISC 3.1 to determine if it would make a difference in the results. In the stepwise analysis, the measurement LIFL was left out and the correct classification accuracy was the same as the non-stepwise analysis, meaning that LIFL added little to the sex estimation (Table 6).

FORDISC 3.1 and R 3.3.2 Analyses Comparison

I used discriminant analysis in R 3.3.2 (Ripley et al. 2015) on the samples established for the FORDISC 3.1 analyses to see if the results were the same (Table 6). The R 3.3.2 analyses I conducted were non-stepwise and focused only on the measurements selected from the discriminant analyses in FORDISC 3.1.

Table 1. Sample University of Tennessee (UT) identification numbers, age, and sex. Sample list provided by Dr. Dawnie Steadman.

UT Identification Number	Age	Sex
UT01-00D	40 years	Male
UT01-01D	84 years	Male
UT01-02D	96 years	Male
UT01-03D	47 years	Male
UT01-05D	44 years	Male
UT01-06D	71 years	Male
UT01-08D	77 years	Male
UT01-09D	93 years	Female
UT01-10D	63 years	Female
UT01-83D	79 years	Female
UT01-88D	71 years	Female
UT01-93D	53 years	Female
UT01-94D	45 years	Male
UT01-97D	79 years	Male
UT02-00D	58 years	Male
UT02-04D	68 years	Male
UT02-07D	81 years	Male
UT02-08D	64 years	Female
UT02-10D	76 years	Male
UT02-87D	75 years	Male
UT02-89D	36 years	Male
UT02-92D	62 years	Female
UT02-94D	72 years	Male
UT02-95D	80 years	Female
UT02-96D	87 years	Male
UT03-02D	76 years	Male
UT03-05D	59 years	Male
UT03-06D	52 years	Female
UT03-83D	63 years	Male
UT03-90D	43 years	Male
UT03-98D	88 years	Male
UT03-99D	66 years	Female
UT04-00D	57 years	Male
UT04-02D	60 years	Female
UT04-05D	72 years	Male
UT04-06D	58 years	Female

Table 1 continued

UT Identification Number	Age	Sex
UT04-09D	68 years	Female
UT04-10D	35 years	Male
UT04-87D	55 years	Male
UT04-89D	51 years	Male
UT04-94D	101 years	Male
UT04-96D	55 years	Male
UT04-97D	33 years	Male
UT04-98D	55 years	Male
UT05-00D	88 years	Male
UT05-03D	61 years	Male
UT05-04D	72 years	Male
UT05-05D	49 years	Male
UT05-06D	unknown	Male
UT05-07D	72 years	Female
UT05-09D	59 years	Male
UT05-10D	61 years	Female
UT05-83D	48 years	Male
UT05-87D	53 years	Female
UT05-88D	unknown	Male
UT05-97D	67 years	Female
UT05-99D	38 years	Male
UT06-01D	66 years	Male
UT06-10D	71 years	Female
UT06-92D	62 years	Female
UT06-93D	80 years	Female
UT07-92D	64 years	Female
UT07-96D	57 years	Female
UT07-97D	32 years	Female
UT08-09D	49 years	Female
UT09-00D	43 years	Female
UT09-95D	64 years	Female
UT100-09D	50 years	Female
UT101-06D	60 years	Female
UT110-08D	73 years	Female
UT110-10D	80 years	Female
UT11-01D	88 years	Female
UT11-04D	54 years	Female

Table 1 continued

UT Identification Number	Age	Sex
UT11-05D	76 years	Female
UT11-06D	60 years	Female
UT11-08D	79 years	Female
UT111-07D	50 years	Female
UT111-08D	75 years	Female
UT11-11D	46 years	Female
UT112-07D	64 years	Female
UT112-08D	97 years	Female
UT113-07D	75 years	Female
UT113-10D	45 years	Female

Table 2. Dimensions of the base of the occipital condyles and foramen magnum, atlas, and axis that were used to estimate sex. I measured these dimensions on skeletal remains of 83 white humans accessioned in the William M. Bass Skeletal Collection at the University of Tennessee, Knoxville. Twenty-four of these dimensions were used in previous studies to estimate sex of skeletal remains. The original use is indicated by the superscript. I developed six of the dimensions for this study. Abbreviation = Abbr.

Dimension Measured	**Abbr**
Maximum length of the right occipital condyle as measured along the long axis from the edges of the articular surface.	MLCR[1]
Maximum length of the left occipital condyle as measured along the long axis from the edges of the articular surface.	MLCL[1]
Minimum distance between the medial edges of the articular surfaces of the occipital condyles.	MND[1]
Bicondylar breadth measured as the maximum distance between the lateral edges of the articular surfaces of the occipital condyles.	BCB[1]
Maximum interior distance between the medial articular margins of the occipital condyles.	MXID[1]
Maximum internal length of the foramen magnum as measured along the midsagittal plane.	LFM[1]
Maximum internal width of the foramen magnum as measured perpendicular to the midsagittal plane.	WFM[1]
Maximum length of the right superior facet of the atlas as measured from the distal and proximal edges of the facet.	LSFR[2]
Maximum length of the left superior facet of the atlas as measured from the distal and proximal edges of the facet.	LSFL[2]
Maximum length of the right inferior facet of the atlas as measured from the distal and proximal edges of the facet.	LIFR[2]
Maximum length of the left inferior facet of the atlas as measured from the distal and proximal edges of the facet.	LIFL[2]
Maximum width of the right inferior facet of the atlas as measured from the medial and lateral edges of the facet.	WIFR[2]
Maximum width of the left inferior facet of the atlas as measured from the medial and lateral edges of the facet.	WIFL[2]
Maximum distance between the lateral edges of the superior facets of the atlas.	MXDS[2]
Maximum distance between the lateral edges of the inferior facets of the atlas.	MXDI[2]
Maximum length of the vertebral foramen of the atlas as measured from fovea (anterior) to posterior arch.	LVC1[2]

Table 2 continued

Dimension Measured	Abbr
Maximum sagittal length of the axis as measured from the most anterior point on the body to the posterior edge of the spinous process.	XSL[3]
Maximum height of the dens of the axis as measured from the most inferior edge of the anterior border of the body to the most superior point on the dens.	XDH[3]
Maximum sagittal diameter of the dens of the axis as measured anterior to posterior.	DSD[3]
Transverse diameter of the dens of the axis as measured perpendicular to the sagittal diameter.	DTD[3]
Internal length of the vertebral foramen of the axis as measured at the inferior edge of the foramen in the median plane.	LVFC2[3]
Maximum breadth between the superior articular facets of the axis as measured from the most lateral edges of the superior facets.	SFB[3]
Maximum sagittal diameter of the right superior articular facet of the axis.	SFSR[3]
Maximum sagittal diameter of the left superior articular facet of the axis.	SFSL[3]
Minimum distance between the medial tubercles inside the vertebral foramen of the atlas.	MDMT[4]
Minimum interior distance between the superior articular facets of the atlas as measured from the medial edges of the superior tips of the facets.	MDSF[4]
Minimum interior distance between the inferior articular facets of the axis as measured from the medial edges.	MDIF[4]
Minimum distance between the transverse foramina on the superior surface of the axis as measured from the medial edges of the foramina (if there are multiple foramina, use most medial ones).	MITS[4]
Minimum distance between the superior articular facets of the axis as measured from the medial edges of the superior tips of the facets.	MDSA[4]
The maximum distance between the transverse foramina on the inferior surface of the axis. Measured from the lateral edges of the foramina (if there are multiple foramina, I used the most medial ones).	MATI[4]

[1]Holland (1986 a), [2]Marino 1995, [3]Wescott 2000, [4]new measurement

CHAPTER III: RESULTS

R 3.3.2 Measurement Repeatability and Bilateral Tests Results

I found no significant difference in any of my repeated measurements, indicating that my measurements were replicable ($\alpha = 0.05$; Table 3). I also found no significant difference between left and right sides for the dimensions of MLC, LSF, LIF, and SFS ($\alpha = 0.05$; Table 4). I did find a difference between the left and right sides for the WIF measurement ($\alpha = 0.05$; Table 4).

FORDISC 3.1 Individual Measurement Discriminant Analyses Results

The highest classification accuracy levels calculated in FORDISC 3.1 were found in WIFL (females = 90.5%, males = 76.3%, overall = 83.8%), XDH (males = 81.1%, females = 87.8%, overall = 84.6%), XSL (females = 85.4%, males = 75.0%, overall = 80.5%), SFB (females = 80.0%, males = 74.4%, overall = 77.2%), and WIFR (females = 76.9%, males = 76.3%, overall = 76.6%) (Table 5). Of the new measurements analyzed in FORDISC 3.1 for this study, only MATI exhibits slight sex estimation potential with females classified 70.6% accuracy, males classified with 74.3% accuracy, and combined are classified with 72.5% accuracy (Table 3).

FORDISC 3.1 Measurement Combination Discriminant Analyses Results

The occipital bone and atlas had very similar levels of sex estimation classification accuracy analyzed in FORDISC 3.1 with the occipital bone at 77% and the atlas from 76.9 – 80.0% (Table 6). The new measurement combination was less sexually dimorphic then the occipital bone, atlas, and axis combinations with an accuracy rate of 66.7% – 68.8% (Table 6). The axis was the most sexually dimorphic bone analyzed in FORDISC 3.1 from this study, with a sex estimation classification accuracy of 89.2%

(Table 6). In the combinations from all three bones, three of the measurements came from the axis (Table 6). Only one measurement was included from the occipital bone and one from the atlas in the combination from all three bones (Table 6). In the 70 individuals sampled with stepwise technique applied, only the LFM from the occipital bone was included with the axis dimensions (Table 6). All sets of combinations (occipital, atlas, axis, and all three combined analyses) produced significant differences between males and females ($\alpha = 0.001$; Table 6).

The best combination of occipital measurements selected in FORDISC 3.1 for estimating sex of skeletal remains was MLCL, WFM, MND, MLCR, LFM, and MXID, which accurately estimated 80.0% of the females, 74.2% of males, and 77.0% combined (Table 6). The percentage weights, how much each measurement contributed to the sex estimation, for each dimension was MLCL (27.1%), WFM (22.2%), MND (13.9%), MLCR (16.6%), LFM (10.6%), and MXID (9.6%) (Table 6). My analysis performed in R 3.3.2 produced identical results (Table 6).

The combination of atlas measurements selected in FORDISC 3.1 that best estimated sex was WIFL, LSFL, LIFR, LIFL, LSFR, LVFC1, and MXDI. This combination of measurements predicted the sex of females with 77.4% accuracy, of males with 76.5% accuracy, and a combined classification accuracy of 76.9% (Table 6). The percentage weight that each measurement contributed was WIFL (32.0%), LSFL (16.0%), LIFR (19.9%), LIFL (13.1%), LSFR (6.2%), LVFC1 (3.6%), and MXDI (9.2%) (Table 6). The analysis I ran in R 3.3.2 classified females accurately at 77.4%, males at 82.4%, and combined with 80.0% (Table 6).

The combination of axis measurements selected in FORDISC 3.1 that most accurately predicted the sex of the individuals was XSL, XDH, DSD, and SFSR (Table 6). This combination of measurements classified females with 94.3% accuracy, males with 83.3% accuracy, and males and females combined with an 89.2% accuracy (Table 6). The percentage weights that each measurement contributed were XSL (34.9%), XDH (25.8%), DSD (22.0%), and SFSR (17.3%) (Table 6). My analysis in R 3.3.2 produced identical results (Table 6).

The combination of new measurements selected in FORDISC 3.1 was MATI, MDSA, MITS, MDMT, and MDSF (Table 6). This combination classified females with an 69.6% accuracy, males with 64.0%, and males and females combined with an 66.7% accuracy (Table 6). The percentage weights that each measurement contributed were MATI (35.6%), MDSA (20.7%), MITS (31.4%), MDMT (6.2%), and MDSF (6.1%) (Table 6). My analysis in R 3.3.2 classified females with an accuracy of 69.6%, males with 68.0%, and males and females combined with an 68.8% accuracy (Table 6).

The analyses (occipital, alas, and axis combined) I performed in FORDISC 3.1 from a sample size of 35 classified females correctly with an 93.8% accuracy, males with an 94.7% accuracy, and a combined accuracy of 94.3% (Table 6). My results from R 3.3.2 were identical to the FORDISC 3.1 results (Table 6).

The next analyses were from a sample size of 70 (one with only five measurements and one with four measurements). A discriminant analysis I performed in FORDISC 3.1 (non-stepwise), classified females correctly with an accuracy of 87.5%, males 86.7%, and combined 87.1% (Table 6). The percentage weights of each measurement calculated by FORDISC 3.1 were LFM (9.9%), LIFL (2.3%), SFSL

(20.4%), XDH (29.1%), and XSL (38.3%) (Table 6). The stepwise analysis with only four measurements selected by FORDISC 3.1 produced identical classification accuracies and the percentage weights were XSL (40.7%), XDH (30.2%), LFM (10.1%), and SFSL (19.0%) (Table 6). The analyses I performed in R 3.3.2 classified females correctly with an accuracy of 90.0%, males with 86.7%, and combined 88.6% for both analyses (one with five measurements and one with four measurements) (Table 6).

Two of the measurements I analyzed with the lowest sex estimation potential were the atlas LSFR measurement and the axis MDSA measurement (Table 5; Figures 1, 2). The LSFR and MDSA measurements did not have the lowest combined classification accuracies produced by FORDISC 3.1, but the classification accuracy results for males and females were both below 60% (Table 5; Figures 1, 2). The five measurements that were selected by FORDISC 3.1 in my stepwise discriminate analysis to have the highest sex estimation potential when combined were LFM, LIFL, SFSL, XDH, XSL (Table 6; Figures 3, 4, 5, 6, 7).

FORDISC 3.1 and R 3.3.2 Analyses Comparison Results

The results from the R 3.3.2 calculations were identical to the FORDISC 3.1 results except for two instances (Table 6). Two males were misclassified as females in the atlas analysis in FORDISC 3.1 that were not misclassified in R 3.3.2 (Table 6). One male from my new measurements analyses was misclassified by FORDISC 3.1 that was not misclassified by R 3.3.2 (Table 6). Also, one female was misclassified in FORDISC 3.1, but not in R 3.3.2 in the analyses from a sample of 70 individuals (Table 6).

Table 3. Measurement repeatability results for the occipital bone, atlas, and axis dimensions. The number of individuals in the analysis are recorded in parenthesis after each standard deviation (*SD*). Standard error of the mean = *SEM*. Abbreviations = Abbr and significance = S.

Abbr	**Mean ± *SD* and *SEM*: ± in mm**	***p* Value, Significance Comparison, and Wilcoxon *V* Value**
MLCR	**Initial:** 23.18 ± 3.56 (3) *SEM*: ± 2.06 **Remeasured:** 23.05 ± 3.58 (3) *SEM*: ± 2.07	$p = 0.75$ ($p > 0.05$) **S:** No $V = 4$
MLCL	**Initial:** 23.93 ± 3.81 (3) *SEM*: ± 2.20 **Remeasured:** 23.63 ± 3.52 (3) *SEM*: ± 2.03	$p = 0.25$ ($p > 0.05$) **S:** No $V = 6$
MND	**Initial:** 18.93 ± 0.96 (3) *SEM*: ± 0.55 **Remeasured:** 18.90 ± 0.75 (3) *SEM*: ± 0.43	$p = 1.00$ ($p > 0.05$) **S:** No $V = 3$
BCB	**Initial:** 50.13 ± 3.24 (3) *SEM*: ± 1.87 **Remeasured:** 50.16 ± 3.25 (3) *SEM*: ± 1.88	$p = 1.00$ ($p > 0.05$) **S:** No $V = 3$
MXID	**Initial:** 31.63 ± 1.99 (3) *SEM*: ± 1.15 **Remeasured:** 31.74 ± 1.76 (3) *SEM*: ± 1.02	$p = 1.00$ ($p > 0.05$) **S:** No $V = 3$
LFM	**Initial:** 35.78 ± 3.18 (3) *SEM*: ± 1.84 **Remeasured:** 35.70 ± 3.12 (3) *SEM*: ± 1.80	$p = 0.25$ ($p > 0.05$) **S:** No $V = 6$
WFM	**Initial:** 30.81 ± 3.14 (3) *SEM*: ± 1.82 **Remeasured:** 30.40 ± 2.77 (3) *SEM*: ± 1.60	$p = 0.25$ ($p > 0.05$) **S:** No $V = 6$
LSFR	**Initial:** 22.45 ± 3.97 (2) *SEM*: ± 2.82 **Remeasured:** 22.29 ± 3.80 (2) *SEM*: ± 2.70	$p = 0.50$ ($p > 0.05$) **S:** No $V = 3$

Table 3 continued

Abbr	Mean ± *SD* and *SEM*: ± in mm	*p* Value, Significance Comparison, and Wilcoxon *V* Value
LSFL	**Initial:** 23.26 ± 3.55 (3) *SEM*: ± 2.05 **Remeasured:** 23.04 ± 3.64 (3) *SEM*: ± 2.10	$p = 0.50$ ($p > 0.05$) **S:** No $V = 5$
LIFR	**Initial:** 19.09 ± 2.33 (3) *SEM*: ± 1.35 **Remeasured:** 18.89 ± 2.08 (3) *SEM*: ± 1.20	$p = 0.50$ ($p > 0.05$) **S:** No $V = 5$
LIFL	**Initial:** 18.93 ± 2.15 (3) *SEM*: ± 1.24 **Remeasured:** 19.01 ± 2.17 (3) *SEM*: ± 1.25	$p = 0.1736$ ($p > 0.05$) **S:** No $V = 0$
WIFR	**Initial:** 14.46 ± 1.50 (3) *SEM*: ± 0.87 **Remeasured:** 14.60 ± 1.36 (3) *SEM*: ± 0.79	$p = 0.25$ ($p > 0.05$) **S:** No $V = 0$
WIFL	**Initial:** 14.39 ± 1.49 (3) *SEM*: ± 0.86 **Remeasured:** 14.42 ± 1.44 (3) *SEM*: ± 0.83	$p = 1.00$ ($p > 0.05$) **S:** No $V = 3$
MXDS	**Initial:** 46.95 ± 4.57 (2) *SEM*: ± 3.24 **Remeasured:** 47.12 ± 4.73 (2) *SEM*: ± 3.35	$p = 0.50$ ($p > 0.05$) **S:** No $V = 0$
MXDI	**Initial:** 44.05 ± 3.02 (3) *SEM*: ± 1.75 **Remeasured:** 44.03 ± 3.03 (3) *SEM*: ± 1.75	$p = 0.25$ ($p > 0.05$) **S:** No $V = 6$
LVFC1	**Initial:** 30.53 ± 0.73 (3) *SEM*: ± 0.42 **Remeasured:** 30.60 ± 0.61 (3) *SEM*: ± 0.35	$p = 1.00$ ($p > 0.05$) **S:** No $V = 3$

Table 3 continued

Abbr	Mean ± *SD* and *SEM*: ± in mm	*p* Value, Significance Comparison, and Wilcoxon *V* Value
XSL	**Initial:** 49.52 ± 2.53 (3) *SEM*: ± 1.46 **Remeasured:** 49.50 ± 2.40 (3) *SEM*: ± 1.39	$p = 0.75$ ($p > 0.05$) **S:** No $V = 4$
XDH	**Initial:** 38.53 ± 1.32 (3) *SEM*: ± 0.76 **Remeasured:** 38.28 ± 1.28 (3) *SEM*: ± 0.74	$p = 0.25$ ($p > 0.05$) **S:** No $V = 6$
DSD	**Initial:** 11.34 ± 0.72 (3) *SEM*: ± 0.42 **Remeasured:** 11.29 ± 0.78 (3) *SEM*: ± 0.45	$p = 0.50$ ($p > 0.05$) **S:** No $V = 5$
DTD	**Initial:** 10.62 ± 0.76 (3) *SEM*: ± 0.44 **Remeasured:** 10.61 ± 0.73 (3) *SEM*: ± 0.42	$p = 1.00$ ($p > 0.05$) **S:** No $V = 3$
LVFC2	**Initial:** 15.04 ± 0.94 (3) *SEM*: ± 0.54 **Remeasured:** 15.08 ± 0.89 (3) *SEM*: ± 0.51	$p = 0.75$ ($p > 0.05$) **S:** No $V = 2$
SFB	**Initial:** 43.68 ± 4.46 (3) *SEM*: ± 2.58 **Remeasured:** 43.67 ± 4.42 (3) *SEM*: ± 2.55	$p = 1.00$ ($p > 0.05$) **S:** No $V = 3$
SFSR	**Initial:** 17.88 ± 1.26 (3) *SEM*: ± 0.73 **Remeasured:** 17.70 ± 1.11 (3) *SEM*: ± 0.64	$p = 0.25$ ($p > 0.05$) **S:** No $V = 6$
SFSL	**Initial:** 18.03 ± 1.95 (3) *SEM*: ± 1.13 **Remeasured:** 17.91 ± 1.92 (3) *SEM*: ± 1.11	$p = 1.00$ ($p > 0.05$) **S:** No $V = 3$

Table 3 continued

Abbr	Mean ± *SD* and *SEM*: ± in mm	*p* Value, Significance Comparison, and Wilcoxon *V* Value
MDMT	**Initial:** 14.47 ± 1.14 (3) *SEM*: ± 0.66 **Remeasured:** 14.33 ± 0.96 (3) *SEM*: ± 0.55	$p = 0.50$ ($p > 0.05$) **S:** No $V = 5$
MDSF	**Initial:** 18.80 ± 0.89 (3) *SEM*: ± 0.51 **Remeasured:** 18.71 ± 0.87 (3) *SEM*: ± 0.50	$p = 0.25$ ($p > 0.05$) **S:** No $V = 6$
MDIF	**Initial:** 24.81 ± 1.08 (3) *SEM*: ± 0.62 **Remeasured:** 24.80 ± 0.97 (3) *SEM*: ± 0.56	$p = 1.00$ ($p > 0.05$) **S:** No $V = 3$
MITS	**Initial:** 37.51 ± 0.68 (3) *SEM*: ± 0.39 **Remeasured:** 37.54 ± 0.69 (3) *SEM*: ± 0.40	$p = 1.00$ ($p > 0.05$) **S:** No $V = 1$
MDSA	**Initial:** 13.54 ± 0.82 (3) *SEM*: ± 0.47 **Remeasured:** 13.49 ± 0.91 (3) *SEM*: ± 0.53	$p = 0.75$ ($p > 0.05$) **S:** No $V = 4$
MATI	**Initial:** 37.61 ± 2.34 (3) *SEM*: ± 1.35 **Remeasured:** 37.80 ± 2.60 (3) *SEM*: ± 1.50	$p = 0.50$ ($p > 0.05$) **S:** No $V = 1$

Table 4. Bilateral comparison results for side and sex. The number of individuals in the analysis are recorded in parenthesis after each standard deviation (*SD*). Standard error of the mean = *SEM*. R = right side, L = left side, FR = female right side, FL = female left side, MR = male right side, ML = male left side, abbreviation = abbr, and significance = S.

Abbr	**Left and Right Mean ± *SD* and *SEM* ± in mm, *p* Value, Significance Comparison, and Wilcoxon *V* Value**	**Female and Male Right Mean ± *SD* and *SEM* ± in mm, *p* Value, Significance Comparison, and Wilcoxon *V* Value**	**Female and Male Left Mean ± *SD* and *SEM* ± in mm, *p* Value, Significance Comparison, and Wilcoxon *V* Value**
MLC	**R:** 24.76 ± 2.35 (70) *SEM*: ± 0.28 **L:** 24.41 ± 2.73 (70) *SEM*: ± 0.33 *p* = 0.1899 (*p* > 0.05) **S:** No *V* = 1467	**FR:** 24.10 ± 2.07 (34) *SEM*: ± 0.36 **MR:** 25.60 ± 2.29 (34) *SEM*: ± 0.39 *p* = 0.00656 (*p* < 0.05) **S:** Yes *V* = 138	**FL:** 23.32 ± 2.11 (34) *SEM*: ± 0.36 **ML:** 25.61 ± 2.86 (34) *SEM*: ± 0.49 *p* = 0.0002217 (*p* < 0.05) **S:** Yes *V* = 81
LSF	**R:** 23.55 ± 2.23 (77) *SEM*: ± 0.25 **L:** 23.52 ± 2.41 (77) *SEM*: ± 0.27 *p* = 0.5852 (P > 0.05) **S:** No *V* = 1609.5	**FR:** 22.82 ± 2.08 (38) *SEM*: ± 0.34 **MR:** 24.24 ± 2.19 (38) 0.36 *p* = 0.01236 (*p* < 0.05) **S:** Yes *V* = 197.5	**FL:** 22.48 ± 1.93 (38) *SEM*: ± 0.31 **ML:** 24.52 ± 2.46 (38) *SEM*: ± 0.40 *p* = 0.0002299 (*p* < 0.05) **S:** Yes *V* = 116
LIF	**R:** 18.88 ± 1.80 (77) *SEM*: ± 0.21 **L:** 18.68 ± 1.86 (77) *SEM*: ± 0.21 *p* = 0.05891 (*p* > 0.05) **S:** No *V* = 1874	**FR:** 18.15 ± 1.66 (38) *SEM*: ± 0.27 **MR:** 19.69 ± 1.57 (38) *SEM*: ± 0.25 *p* = 0.0001864 (*p* < 0.05) **S:** Yes *V* = 124	**FL:** 18.21 ± 1.81 (38) *SEM*: ± 0.29 **ML:** 19.22 ± 1.76 (38) *SEM*: ± 0.29 *p* = 0.005731 (*p* < 0.05) **S:** Yes *V* = 179.5

Table 4 continued

Abbr	Left and Right Mean ± *SD* and *SEM* ± in mm, *p* Value, Significance Comparison, and Wilcoxon *V* Value	Female and Male Right Mean ± *SD* and *SEM* ± in mm, *p* Value, Significance Comparison, and Wilcoxon *V* Value	Female and Male Left Mean ± *SD* and *SEM* ± in mm, *p* Value, Significance Comparison, and Wilcoxon *V* Value
WIF	**R:** 15.91 ± 1.55 (79) *SEM*: ± 0.17 **L:** 15.63 ± 1.59 (79) *SEM*: ± 0.18 *p* = 0.03735 (*p* < 0.05) **S:** Yes *V* = 2006.5	**FR:** 15.08 ± 1.26 (39) *SEM*: ± 0.20 **MR:** 16.75 ± 1.37 (39) *SEM*: ± 0.22 *p* = 9.39e-06 (*p* < 0.05) **S:** Yes *V* = 72	**FL:** 14.75 ± 1.19 (39) *SEM*: ± 0.19 **ML:** 16.58 ± 1.38 (39) *SEM*: ± 0.22 *p* = 1.637e-07 (*p* < 0.05) **S:** Yes *V* = 53
SFS	**R**: 18.14 ± 1.77 (81) *SEM*: ± 0.20 **L**: 18.12 ± 1.87 (81) *SEM*: ± 0.21 *p* = 0.7364 (*p* > 0.05) **S:** No *V* = 1732.5	**FR:** 17.24 ± 1.40 (40) *SEM*: ± 0.22 **MR:** 19.08 ± 1.64 (40) *SEM*: ± 0.26 *p* = 2.04e-07 (*p* < 0.05) **S:** Yes *V* = 61	**FL:** 17.21 ± 1.45 (40) *SEM*: ± 0.23 **ML:** 19.08 ± 1.79 (40) *SEM*: ± 0.28 *p* = 1.127e-05 (*p* < 0.05) **S:** Yes *V* = 104

Table 5. Classification accuracy for each measurement. The number of individuals in the analysis are recorded in parenthesis after each standard deviation (*SD*). Standard error of the mean = *SEM*. Abbreviation = abbr, females = F, and males = M.

Abbr	**Female and Male Mean ± *SD* and *SEM* ±**	**Classification Accuracy**
MLCR	**F:** 23.82 ± 2.00 (36) *SEM*: ± 0.33 **M:** 25.24 ± 2.26 (38) *SEM*: ± 0.37	**F:** 66.7% (24 / 36) **M:** 73.7% (28 / 38) **Overall:** 70.3% (52 / 74) $p < 0.006$
MLCL	**F:** 23.39 ± 2.16 (39) *SEM*: ± 0.35 **M:** 25.58 ± 2.90 (33) *SEM*: ± 0.51	**F:** 64.1% (25 / 39) **M:** 69.7% (23 / 33) **Overall:** 66.7% (48 / 72) $p < 0.001$
MND	**F:** 20.00 ± 2.55 (34) *SEM*: ± 0.44 **M:** 21.25 ± 2.94 (35) *SEM*: ± 0.50	**F:** 64.7% (22 / 34) **M:** 42.9% (15 / 35) **Overall:** 53.6% (37 / 69) $p < 0.063$
BCB	**F:** 50.86 ± 2.77 (39) *SEM*: ± 0.44 **M:** 52.95 ± 3.33 (36) *SEM*: ± 0.56	**F:** 69.2% (27 / 39) **M:** 58.3% (21 / 36) **Overall:** 64.0% (48 / 75) $p < 0.004$
MXID	**F:** 32.48 ± 2.39 (41) *SEM*: ± 0.37 **M:** 33.40 ± 2.13 (38) *SEM*: ± 0.35	**F:** 48.8% (20 / 41) **M:** 60.5% (23 / 38) **Overall:** 54.4% (43 / 79) $p < 0.078$
LFM	**F:** 35.44 ± 2.57 (42) *SEM*: ± 0.40 **M:** 36.91 ± 2.65 (38) *SEM*: ± 0.43	**F:** 66.7% (28 / 42) **M:** 63.2% (24 / 38) **Overall:** 65.0% (52 / 80) $p < 0.014$
WFM	**F:** 29.95 ± 2.32 (42) *SEM*: ± 0.36 **M:** 31.58 ± 2.05 (38) *SEM*: ± 0.33	**F:** 61.9% (26 / 42) **M:** 63.2% (24 / 38) **Overall:** 62.5% (50 / 80) $p < 0.001$
LSFR	**F:** 22.84 ± 2.02 (41) *SEM*: ± 0.32 **M:** 24.21 ± 2.10 (39) *SEM*: ± 0.34	**F:** 58.5% (24 / 41) **M:** 53.8% (21 / 39) **Overall:** 56.3% (45 / 80) $p < 0.004$

Table 5 continued

Abbr	Female and Male Mean ± *SD* and *SEM* ±	Classification Accuracy
LSFL	**F:** 22.48 ± 1.93 (38) *SEM*: ± 0.31 **M:** 24.49 ± 2.44 (39) *SEM*: ± 0.39	**F:** 71.1% (27 / 38) **M:** 74.4% (29 / 39) **Overall:** 72.7% (56 / 77) $p < 0.001$
LIFR	**F:** 18.04 ± 1.67 (38) *SEM*: ± 0.27 **M:** 19.60 ± 1.56 (38) *SEM*: ± 0.25	**F:** 68.4% (26 / 38) **M:** 65.8% (25 / 38) **Overall:** 67.1% (51 / 76) $p < 0.001$
LIFL	**F:** 18.11 ± 1.80 (41) *SEM*: ± 0.28 **M:** 19.23 ± 1.75 (38) *SEM*: ± 0.28	**F:** 68.3% (28 / 41) **M:** 57.9% (22 / 38) **Overall:** 63.3% (50 / 79) $p < 0.007$
WIFR	**F:** 15.07 ± 1.26 (39) *SEM*: ± 0.20 **M:** 16.76 ± 1.39 (38) *SEM*: ± 0.23	**F:** 76.9% (30 / 39) **M:** 76.3% (29 / 38) **Overall:** 76.6% (59 / 77) $p < 0.001$
WIFL	**F:** 14.72 ± 1.21 (42) *SEM*: ± 0.19 **M:** 16.57 ± 1.39 (38) *SEM*: ± 0.23	**F:** 90.5% (38 / 42) **M:** 76.3% (29 / 38) **Overall:** 83.8% (67 / 80) $p < 0.001$
MXDS	**F:** 48.58 ± 3.18 (36) *SEM*: ± 0.53 **M:** 51.28 ± 2.96 (38) *SEM*: ± 0.48	**F:** 61.1% (22 / 36) **M:** 60.5% (23 / 38) **Overall:** 60.8% (45 / 74) $p < 0.001$
MXDI	**F:** 45.85 ± 2.50 (38) *SEM*: ± 0.41 **M:** 49.44 ± 2.75 (39) *SEM*: ± 0.44	**F:** 78.9% (30 / 38) **M:** 69.2% (27 / 39) **Overall:** 74.0% (57 / 77) $p < 0.001$
LVFC1	**F:** 30.75 ± 1.91 (37) *SEM*: ± 0.31 **M:** 32.26 ± 2.09 (40) *SEM*: ± 0.33	**F:** 73.0% (27 / 37) **M:** 60.0% (24 / 40) **Overall:** 66.2% (51 / 77) $p < 0.001$

Table 5 continued

Abbr	Female and Male Mean ± *SD* and *SEM* ±	Classification Accuracy
XSL	**F:** 48.16 ± 2.37 (41) *SEM*: ± 0.37 **M:** 52.20 ± 2.54 (36) *SEM*: ± 0.42	**F:** 85.4% (35 / 41) **M:** 75.0% (27 / 36) **Overall:** 80.5% (62 / 77) $p < 0.001$
XDH	**F:** 38.83 ± 2.46 (41) *SEM*: ± 0.38 **M:** 42.92 ± 2.66 (37) *SEM*: ± 0.44	**F:** 87.8% (36 / 41) **M:** 81.1% (30 / 37) **Overall:** 84.6% (66 / 78) $p < 0.001$
DSD	**F:** 11.14 ± 0.76 (42) *SEM*: ± 0.12 **M:** 11.90 ± 0.64 (36) *SEM*: ± 0.11	**F:** 71.4% (30 / 42) **M:** 77.8% (28 / 36) **Overall:** 74.4% (58 / 78) $p < 0.001$
DTD	**F:** 10.55 ± 0.92 (42) *SEM*: ± 0.14 **M:** 11.20 ± 0.81 (37) *SEM*: ± 0.13	**F:** 78.6% (33 / 42) **M:** 67.6% (25 / 37) **Overall:** 73.4% (58 / 79) $p < 0.001$
LVFC2	**F:** 16.58 ± 1.71 (37) *SEM*: ± 0.28 **M:** 16.16 ± 1.69 (37) *SEM*: ± 0.28	**F:** 48.6% (18 / 37) **M:** 64.9% (24 / 37) **Overall:** 56.8% (42 / 74) $p < 0.290$
SFB	**F:** 45.33 ± 2.56 (40) *SEM*: ± 0.41 **M:** 49.09 ± 2.62 (39) *SEM*: ± 0.42	**F:** 80.0% (32 / 40) **M:** 74.4% (29 / 39) **Overall:** 77.2% (61 / 79) $p < 0.001$
SFSR	**F:** 17.23 ± 1.38 (41) *SEM*: ± 0.22 **M:** 19.09 ± 1.66 (39) *SEM*: ± 0.27	**F:** 73.2% (30 / 41) **M:** 76.9% (30 / 39) **Overall:** 75.0% (60 / 80) $p < 0.001$
SFSL	**F:** 17.23 ± 1.44 (42) *SEM*: ± 0.22 **M:** 19.04 ± 1.79 (39) *SEM*: ± 0.29	**F:** 69.0% (29 / 42) **M:** 64.1% (25 / 39) **Overall:** 66.7% (54 / 81) $p < 0.001$

Table 5 continued

Abbr	Female and Male Mean ± *SD* and *SEM* ±	Classification Accuracy
MDMT	**F:** 15.69 ± 1.72 (39) *SEM*: ± 0.28 **M:** 16.19 ± 1.25 (39) *SEM*: ± 0.20	**F:** 64.1% (25 / 39) **M:** 48.7% (19 / 39) **Overall:** 56.4% (44 / 78) $p < 0.146$
MDSF	**F:** 20.07 ± 2.99 (40) *SEM*: ± 0.47 **M:** 21.67 ± 3.58 (34) *SEM*: ± 0.61	**F:** 62.5% (25 / 40) **M:** 55.9% (19 / 34) **Overall:** 59.5% (44 / 74) $p < 0.040$
MDIF	**F:** 25.52 ± 1.37 (30) *SEM*: ± 0.25 **M:** 26.04 ± 1.70 (30) *SEM*: ± 0.31	**F:** 63.3% (19 / 30) **M:** 56.7% (17 / 30) **Overall:** 60.0% (36 / 60) $p < 0.196$
MITS	**F:** 38.93 ± 2.78 (42) *SEM*: ± 0.43 **M:** 41.99 ± 2.94 (40) *SEM*: ± 0.47	**F:** 69.0% (29 / 42) **M:** 70.0% (28 / 40) **Overall:** 69.5% (57 / 82) $p < 0.001$
MDSA	**F:** 15.53 ± 2.15 (36) *SEM*: ± 0.36 **M:** 15.25 ± 1.62 (34) *SEM*: ± 0.28	**F:** 58.3% (21 / 36) **M:** 52.9% (18 / 34) **Overall:** 55.7% (39 / 70) $p < 0.538$
MATI	**F:** 38.96 ± 2.18 (34) *SEM*: ± 0.37 **M:** 41.96 ± 2.76 (35) *SEM*: ± 0.47	**F:** 70.6% (24 / 34) **M:** 74.3% (26 / 35) **Overall:** 72.5% (50 / 69) $p < 0.001$

Table 6. Highest classification accuracy combinations. Number of individuals analyzed are in parentheses. Measurement combination = Combo, female = F, and males = M.

Combo	**FORDISC 3.1 Classification Accuracy**	**R 3.3.2 Classification Accuracy**	**Percentage Weights from FORDISC 3.1 Analyses**
MLCL **WFM** **MND** **MLCR** **LFM** **MXID**	**F:** 80.0% (24 / 30) **M:** 74.2% (23 / 31) **Overall:** 77.0% (47 / 61) $p < 0.001$	**F:** 80.0% (24 / 30) **M:** 74.2% (23 / 31) **Overall:** 77.0% (47 / 61)	MLCL: 27.1% WFM: 22.2% MND: 13.9% MLCR: 16.6% LFM: 10.6% MXID: 9.6%
WIFL **LSFL** **LIFR** **LIFL** **LSFR** **LVFC1** **MXDI**	**F:** 77.4% (24 / 31) **M:** 76.5% (26 / 34) **Overall:** 76.9% (50 / 65) $p < 0.001$	**F:** 77.4% (24 / 31) **M:** 82.4% (28 / 34) **Overall:** 80.0% (52 / 65)	WIFL: 32.0% LSFL: 16.0% LIFR: 19.9% LIFL: 13.1% LSFR: 6.2% LVFC1: 3.6% MXDI: 9.2%
XSL **XDH** **DSD** **SFSR**	**F:** 94.3% (33 / 35) **M:** 83.3% (25 / 30) **Overall:** 89.2% (58 / 65) $p < 0.001$	**F:** 94.3% (33 / 35) **M:** 83.3% (25 / 30) **Overall:** 89.2% (58 / 65)	XSL: 34.9% XDH: 25.8% DSD: 22.0% SFSR: 17.3%
MATI **MDSA** **MITS** **MDMT** **MDSF**	**F:** 69.6% (16 / 23) **M:** 64.0% (16 / 25) **Overall:** 66.7% (32 / 48) $p < 0.003$	**F:** 69.6% (16 / 23) **M:** 68.0% (17 / 25) **Overall:** 68.8% (33 / 48)	MATI: 35.6% MDSA: 20.7% MITS: 31.4% MDMT: 6.2% MDSF: 6.1%
XSL **LFM** **SFSL** **LIFL** **XDH**	**F:** 93.8% (15 / 16) **M:** 94.7% (18 / 19) **Overall:** 94.3% (33 / 35) $p < 0.001$	**F:** 93.8% (15 / 16) **M:** 94.7% (18 / 19) **Overall:** 94.3% (33 / 35)	XSL: 18.2% LFM: 19.6% SFSL: 33.4% LIFL: 6.9% XDH: 21.9%
LFM **LIFL** **SFSL** **XDH** **XSL**	**F:** 87.5% (35 / 40) **M:** 86.7% (26 / 30) **Overall:** 87.1% (61 / 70) $p < 0.001$	**F:** 90.0% (36 / 40) **M:** 86.7% (26 / 30) **Overall:** 88.6% (62 / 70)	LFM: 9.9% LIFL: 2.3% SFSL: 20.4% XDH: 29.1% XSL: 38.3%

Table 6 continued

Combo	FORDISC 3.1 Classification Accuracy	R 3.3.2 Classification Accuracy	Percentage Weights from FORDISC 3.1 Analyses
XSL **XDH** **LFM** **SFSL**	**F:** 87.5% (35 / 40) **M:** 86.7% (26 / 30) **Overall:** 87.1% (61 / 70) $p < 0.001$	**F:** 90.0% (36 / 40) **M:** 86.7% (26 / 30) **Overall:** 88.6% (62 / 70)	XSL: 40.7% XDH: 30.2% LFM: 10.1% SFSL: 19.0%

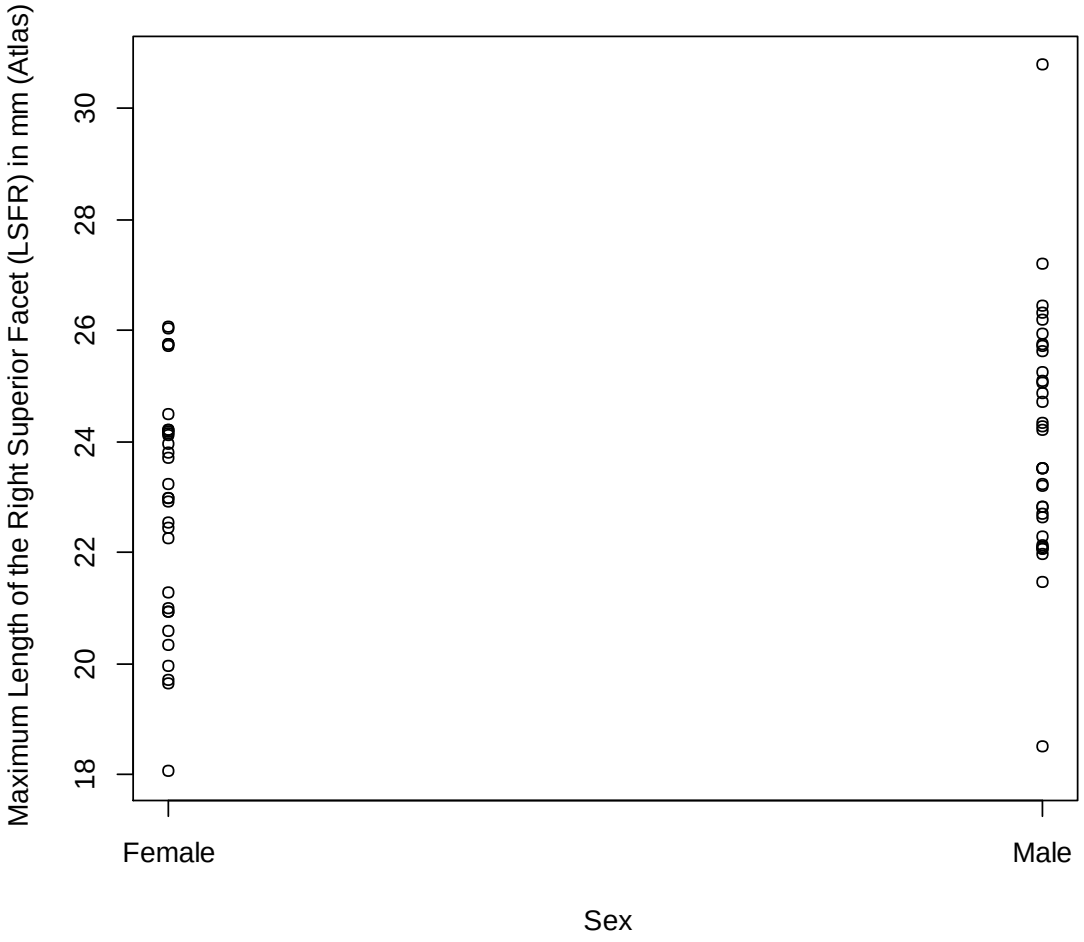

Figure 1. Stripchart of the maximum length of the right superior facet (LSFR) measurement of the atlas. This chart was created in R 3.3.2 from a sample of 65 individuals used in the atlas combination analyses in FORDISC 3.1 and R 3.3.2.

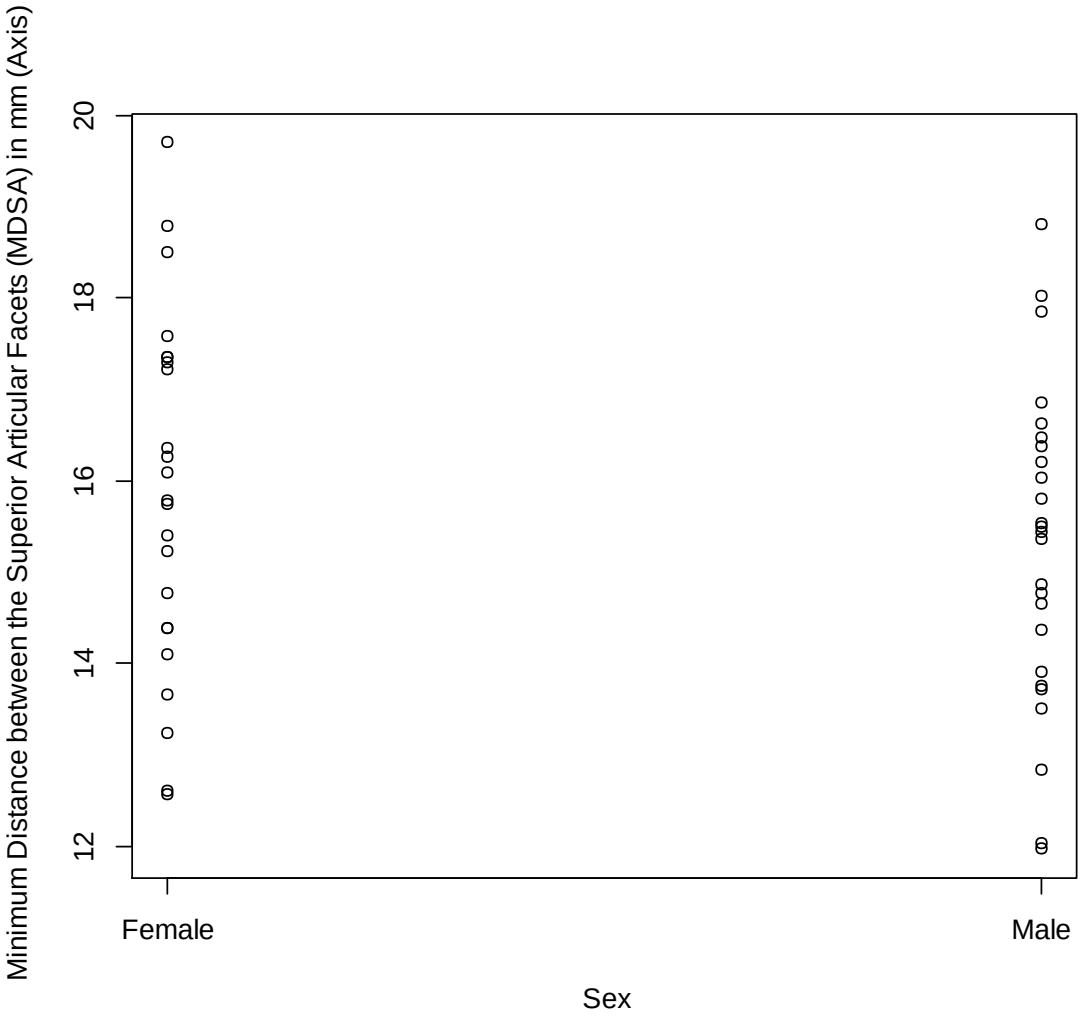

Figure 2. Stripchart of the minimum distance between the superior articular facets (MDSA) measurement of the axis. This chart was created in R 3.3.2 from a sample of 65 individuals used in the axis combination analyses in FORDISC 3.1 and R 3.3.2.

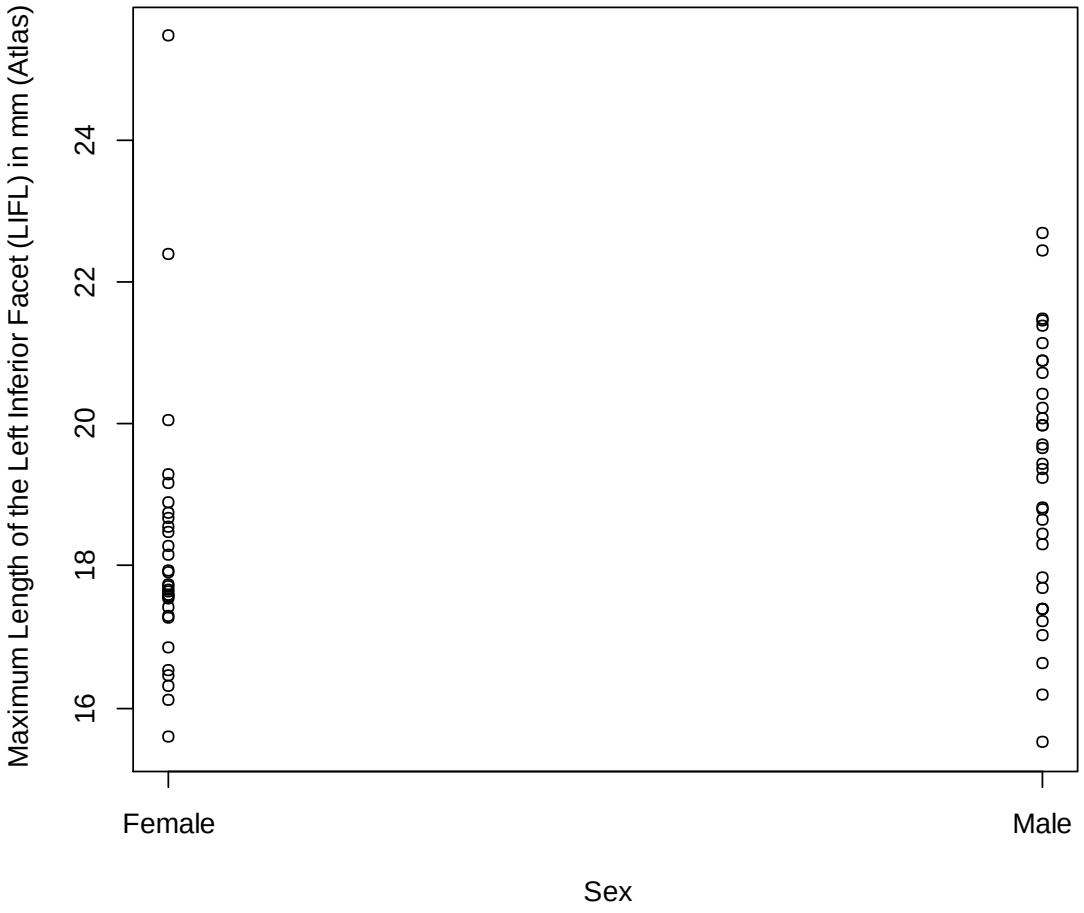

Figure 3. Stripchart of the maximum length of the left inferior facet (LIFL) measurement of the atlas. This chart was created in R 3.3.2 from a sample of 65 individuals used in the atlas combination analyses in FORDISC 3.1 and R 3.3.2.

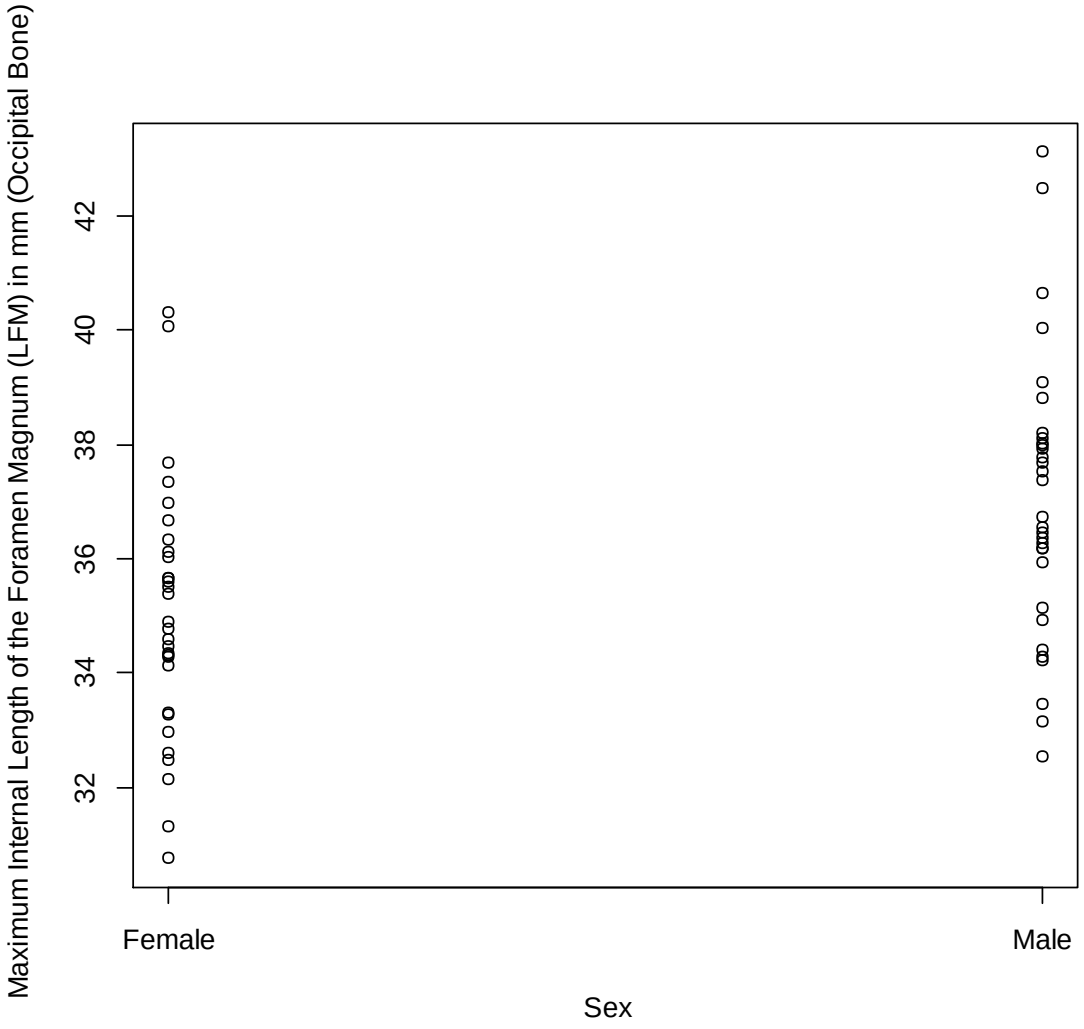

Figure 4. Stripchart of the maximum internal length of the foramen magnum (LFM) measurement of the occipital bone. This chart was created in R 3.3.2 from a sample of 61 individuals used in the occipital bone combination analyses in FORDISC 3.1 and R 3.3.2.

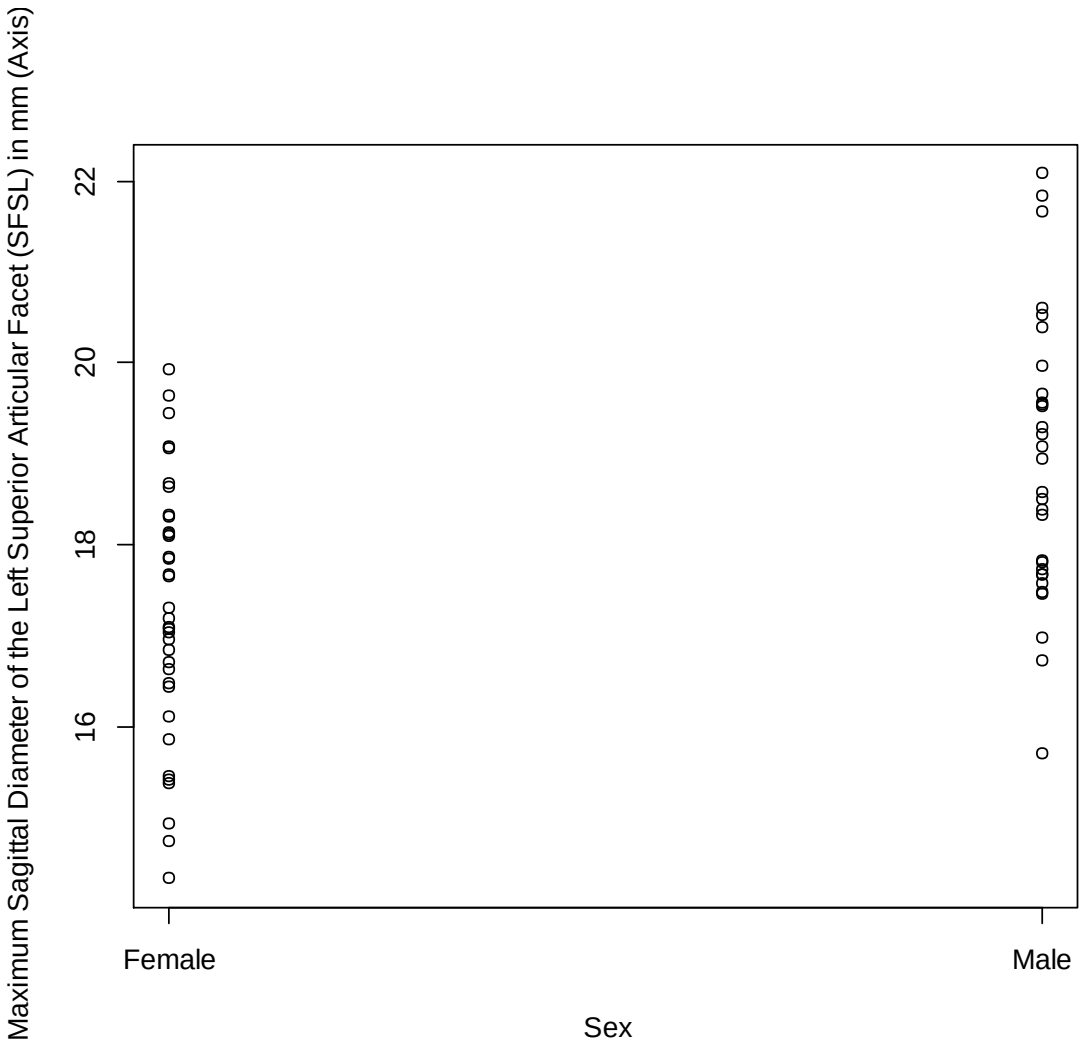

Figure 5. Stripchart of the maximum sagittal diameter of the left superior articular facet (SFSL) measurement of the axis. This chart was created in R 3.3.2 from a sample of 65 individuals used in the axis combination analyses in FORDISC 3.1 and R 3.3.2.

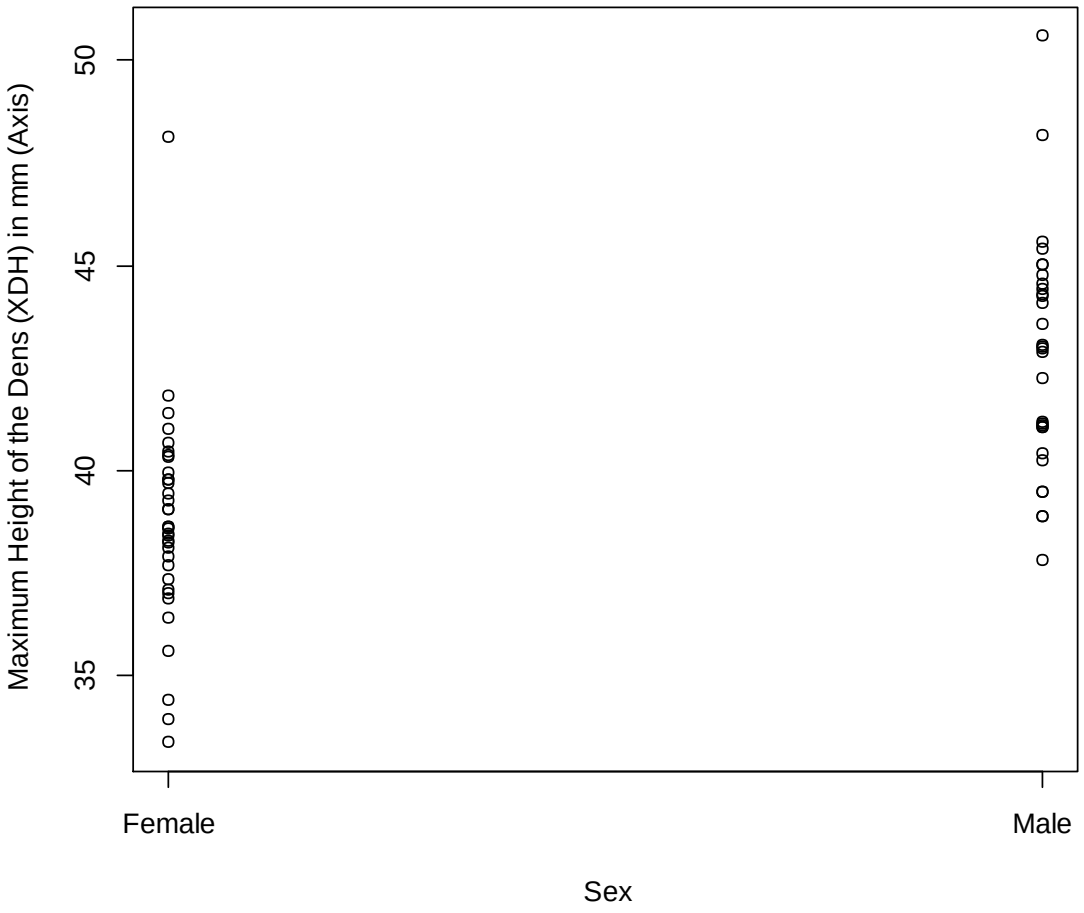

Figure 6. Stripchart of the maximum height of the dens (XDH) measurement of the axis. This chart was created in R 3.3.2 from a sample of 65 individuals used in the axis combination analyses in FORDISC 3.1 and R 3.3.2.

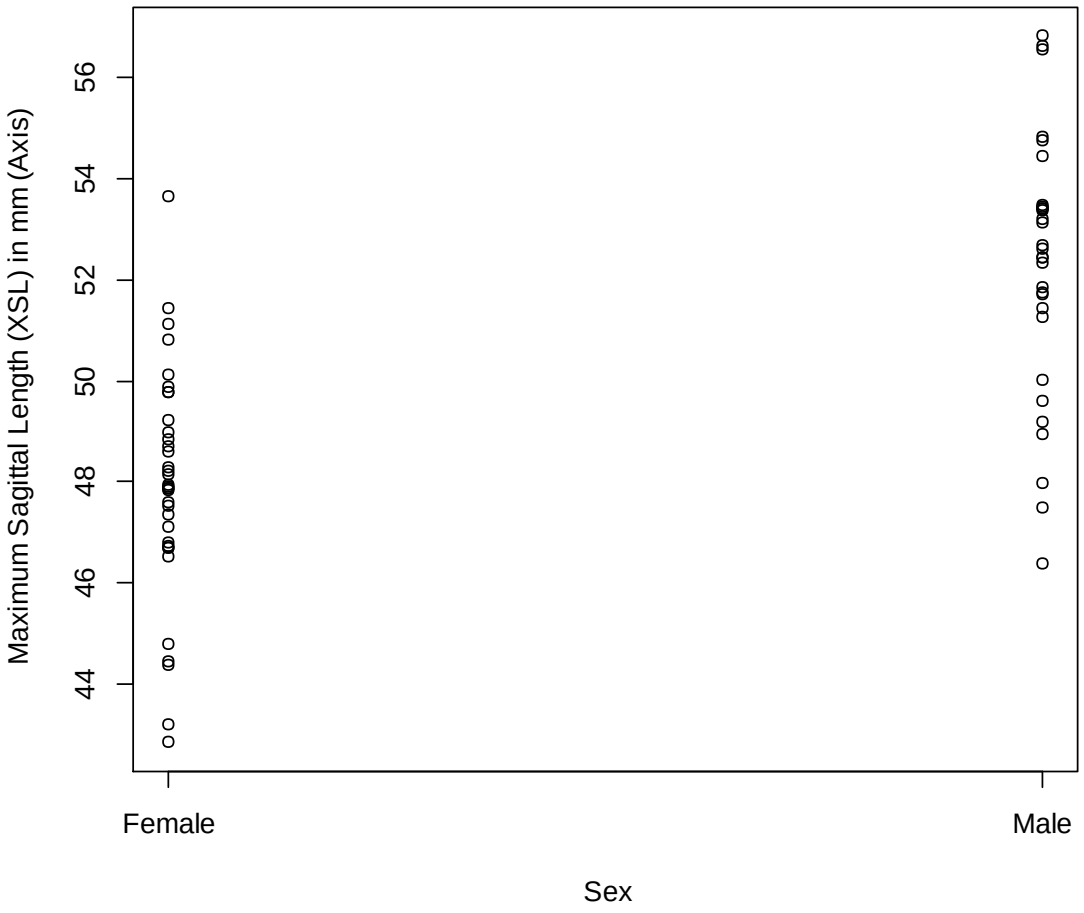

Figure 7. Stripchart of the maximum sagittal length (XSL) measurement of the axis. This chart was created in R 3.3.2 from a sample of 65 individuals used in the axis combination analyses in FORDISC 3.1 and R 3.3.2.

CHAPTER IV: DISCUSSION

Measurement Repeatability and Bilateral Conclusions

My repeatability analysis on all 30 measurements (from three individuals) from this study shows that they are replicable. It is important to note that these measurements produced repeatable results for intra-observer (one observer) results and have not been tested for inter-observer (multiple observers) repeatability (DiGangi and Moore 2013). Only one bilateral measurement in my study (WIF) showed differences between the right and left side. In this instance, the left side (WIFL) exhibits more sex estimating potential than the right side (WIFR).

Measurement Combinations Results Compared to Previous Studies

My accuracy rates of 77.0% (occipital bone), 76.9 – 80.0% (atlas), 89.2% (axis), 66.7 – 68.8% (new measurement combination), 94.3% (sample size of 35 individuals), and 87.1 – 88.6% (sample of 70 individuals) are similar to those reported for previous studies (Holland 1986 a; 70 – 90% (occipital bone), Gapert et al. 2009; 69 – 77% (occipital bone), Marino 1995; 60 – 85% (atlas), Swenson 2013; 76 – 89% (atlas), Wescott 2000; 83% (axis), Marlow and Pastor 2011; 83% (axis), Berthard and Seet 2013; 82 – 87% (axis), Gama et al. 2014; 87 – 90% (axis)). Thus, my findings that the occipital bone, atlas, and axis are useful predictors of sex in adult modern whites from the William M. Bass Skeletal Collection supports the findings of previous researchers (Holland 1986 a, Marino 1995, Wescott 2000, Gapert et al. 2009, Marlow and Pastor 2011, Swenson 2013, Bethard and Seet 2013, Gama et al. 2014). Also, my data indicate that the sex estimation potential of the axis is greater than that of either the occipital bone or the atlas. Furthermore, sex estimation accuracy increases when measurements from the occipital

bone, atlas, and axis are combined, compared to using measurements from only the occipital bone or the atlas in isolation; however, accuracy does not increase with combination measurements (from all three bones) compared to using measurements only from the axis. Rather, analyses of measurements from the axis more accurately estimate sex than do analyses of measurements from combinations of the occipital bone, atlas, and axis. Indeed, the axis is such a powerful estimator of sex that FORDISC 3.1 selected more measurements from the axis than from the atlas and occipital combined or any of my new measurements.

FORDISC 3.1 and R 3.3.2 Results Differences

Analyses from FORDISC 3.1 and R 3.3.2 produce almost identical results. The sex of a few individuals were inaccurately estimated by FORDISC 3.1. In these cases, the posterior probabilities for these individuals are on the border line between male or female classification. Presumably, differences between FORDISC 3.1 and R 3.3.2 result from minor calculation differences that place individuals in either the male or the female category.

Sample Size and Bias

The sample size and possible bias in the study are important to note. One bias in this sample is that most of the individuals were older than 60 years of age. Factors attributed to the aging process such as brittleness, porosity, and excess bone growth may have affected the results (White and Folkens 2005). Brittleness and porosity in bone can cause measurements to be impacted when bits of bone break away from the outer bone margin and thus, could make measurements smaller than they originally were; excess

bone growth can cause measurements to appear larger than they actually are (White and Folkens 2005).

The different accuracy levels reported from the previous studies could have resulted from various researchers looking at different samples, having different sample sizes, or using different statistical tests for their analyses (Holland 1986 a, Marino 1995, Wescott 2000, Gapert et al. 2009, Marlow and Pastor 2011, Berthard and Seet 2013, Swenson 2013, Gama et al. 2014). A difference between the combined (occipital bone, atlas, and axis) analyses for 35 individuals and 70 individuals is that the correct classification accuracy went from 94.3% to 87.1% – 88.6%. Despite the decrease in accurately identifying sex of skeletal remains, the accuracy range is still relatively high. The larger sample size decreases the impact that distortions, such as outliers, have on the analyses. The combined accuracy rates from my study could be affected because I used two different programs (FORDISC 3.1 and R 3.3.2). The FORDISC 3.1 results had the stepwise procedures applied and R 3.3.2 did not; thus, my accuracy ranges may have been impacted by these differences.

Study Limitations and Possible Improvements for Future Research

Financial and time constraints limited my sample size and measurements taken; consequently, my study could be improved with an increase in sample size and time allotted for data collection. Another avenue of research would be to look at other less studied elements of the skeleton to ascertain their sex estimating ability and to look at other populations to see how these classification accuracies change based on different population variations (White and Folkens 2005, DiGangi and Hefner 2013).

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