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Sexual Dimorphism in the Vertebral Column

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To the Graduate Council:

I am submitting herewith a thesis written by Amanda Suzanne Allbright entitled "Sexual Dimorphism in the Vertebral Column." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Anthropology.

Lee Meadows Jantz, Major Professor

We have read this thesis and recommend its acceptance:

Richard Jantz, Murray Marks

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Sexual Dimorphism in the Vertebral Column

A Thesis Presented for the

Master of Arts Degree

The University of Tennessee, Knoxville

Amanda Suzanne Allbright

December 2007

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I would like to thank everyone who has helped me along the way. Most importantly I would like to thank Dr. Lee Meadows Jantz for having patience in helping me over the last two years, I know it was slow, but I finally got it done. Thank you also for access to the Bass Collection. I would also like to thank Dr. Richard Jantz and Dr. Murray Marks for being part of my committee and for their feedback, with special thanks to Dr. Jantz for helping me to understand statistics a little bit better.

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Abstract

Determining sex from skeletal remains is important in forensic and archaeological settings. Though using the pelvis to determine sex is ideal, often remains are fragmentary or incomplete, requiring sex to be estimated from other skeletal elements. Many individual bones have been studied to evaluate sexual dimorphism and the extent to which they can be used to determine sex of an unknown individual. However, sexual dimorphism in the vertebral column has only been examined to a limited extent.

The purpose of this study is to examine the extent of sexual dimorphism throughout the entire vertebral column and, if present, to establish a method by which sex can be determined from any given vertebra, even if the exact vertebral number is not known. A total of 16 different measurements were taken on the vertebrae from a sample of 119 individuals from the William M. Bass Skeletal Collection. Given the small representation of African American individuals in the collection, only individuals of European descent were considered in this study. Since possible effects of aging were to be considered, equal numbers of males and females were randomly selected and matched for age groups. First MANOVA analyses were performed on each vertebrae and vertebral grouping, i.e. cervical C3-C7, thoracic, lumbar, and vertebral column C3-L5, to determine if each was significant for sex for each measurement taken. A stepwise analysis and then discriminant function analysis was performed to select the most sexually dimorphic measurements for each vertebra or vertebral grouping and equations were developed to allow sex to be determined from an unknown individual for each vertebra, or if the vertebral number is not known, from the vertebral grouping.

Table of Contents

List of Tables

List of Figures

Introduction

Since its beginning, the subdiscipline of physical anthropology has focused on identifying and studying variation among and between human populations. Physical anthropologists have studied physical traits, genetic similarities and differences, and skeletal characteristics of individuals and/or groups to compare and contrast variation among people. Study of the skeleton has permitted a better understanding of differences in human groups. Identification of variation in the skeleton allows for the designation of human groupings based on certain characteristics or dimensions. The ability to separate skeletal material on the basis of variation can be utilized to distinguish between ancestry groups, age groups, or sex groups.

In forensic settings involving human skeletal remains, physical anthropologists are often requested to assist in making positive identifications. The first step towards making an identification is providing a biological profile of the individual, including estimations of ancestry, age, and, particularly, sex, by examining the morphology of the bones. Once a possible individual is matched to the remains, a positive identification can be made through several methods, including use of medical and/or dental records and by way of DNA analysis. Morphological analysis usually involves examining the whole skeleton or whole skeletal elements, such as the skull, and looking at the features exhibited overall to provide an estimate of sex. Although the entire skeleton is ideal for determining sex, often remains are incomplete, fragmented or commingled, as is frequently found in archaeological and forensic settings. For this reason, many researchers have examined traits in order to determine sex from individual skeletal elements (Phenice 1969; Ferembach et al. 1980; Krogman and Iscan 1986). Even though sexual dimorphism has been noted on bones throughout the skeleton, the vertebral column has received limited attention. Several studies have noted the ability to estimate sex on one or more vertebrae (Hinck et al. 1962; MacLaughlin and Oldale 1992; Haugen 1994; Marino 1995; Wescott 2000); but no comprehensive study of the entire vertebral column has been initiated. This study seeks to investigate the sexual dimorphism of the entire vertebral column by examining each vertebra through a series of linear measurements and statistical analyses.

Literature Review

Sexual Dimorphism in the Skeleton

Though use of the entire skeleton is optimal for estimating sex of an individual, complete skeletal remains are often not available. Some skeletal elements prove to be better estimators of sex than others and are used when available. Due to sex differences associated with childbearing, the pelvis is recognized as being one of the best areas of the skeleton to determine sex of an individual. Beginning with puberty, the pelves of females start to differentiate to accommodate the process of childbearing. Many of the methods that exist for estimating sex from the pelvis rely upon examining the visual morphology of the bones. One of the most accurate and reliable methods is that developed by Phenice (1969). Phenice describes three morphologies on the pubic bone that can be used to determine sex. The three features Phenice describes are the ischiopubic ramus, ventral arc, and the subpubic concavity. Based on whether the three features are present or absent, an individual will be classified as male, female, or ambiguous with accuracy levels reaching 95% or even higher. Other morphological features of the pelvis may be used to estimate the sex of an individual (Ferembach et al. 1980; Krogman and Iscan 1986; Bass 1995; Listi and Bassett 2006). Visually, male pelves tend to be more massive and rugged with greater marked muscle attachment sites than female pelves. The subpubic angle in males is V-shaped, while in females it is U-shaped. The greater sciatic notch is generally wider and shallower in females than in males. The presence of a preauricular sulcus usually indicates a female. The ilia in males are high and vertical, while in females they are usually lower and laterally divergent. The male sacrum is long and narrow and the female sacrum is short and broad. Males have a heart-shaped pelvic inlet and females have a circular or elliptical inlet (Derry 1912; Ferembach et al. 1980; Krogman and Iscan 1986; Bass 1995).

Metric studies of the pelvis have also been performed (Trotter 1926; Sauter and Private 1952; Hoyme 1957; Ferembach et al. 1980; Segebarth-Orban 1980; Seidler 1980). For example, Sauter and Private [1952 (as cited in Krogman and Iscan 1986)] took two measurements on the pelvis, from the edge of the acetabulum to the adjacent edge of the greater sciatic notch and, perpendicular to this measurement, the sciatic height. The cotylo-sciatic index was then computed by multiplying the first measurement by 100 then dividing by the second measure. If the value was below 123, then the individual would be classified as male, and if the value was above 123 the individual would be classified as female.

Though gross morphological differences in sacrum shape are frequently used to confirm sex determination based on other aspects of the pelvis, used to a lesser extent are statistical analyses of the sacrum. Various measurements of the sacrum have proven useful in determining sex (Fawcett 1938; Flander 1978; Flander and Corruccini 1980; Kimura 1982; Tague 2007). In particular, Flander and Kimura showed that sexual dimorphism exists in the dimensions of the first sacral segment. Flander (1978) found that the anteroposterior aspect and transverse length of the first sacral body were two of the most important variables for discriminating sex. Kimura (1982) developed a base-wing index. The width of the wing of the sacrum is multiplied by 100 then divided by the width of the base, which is the same as the transverse length of the first sacral body. The highest accuracy these two methodologies were able to achieve was in the 70 to low

80s percent range. Sexual variation of the superior aspect of the sacrum suggests that sexual dimorphism may also exist in the lower vertebral column.

In many cases skeletal elements are fragmented or missing, requiring sex to be determined from other skeletal elements. After the pelvis, the cranium has traditionally been considered the next most reliable area of the skeleton for determining sex (Krogman and Iscan 1986, Bass 1995). However, more recent research has provided evidence that the postcranial skeleton estimates sex better than the cranium (France 1998; Spradley and Jantz 2003). Other skeletal elements that have demonstrated sexual variation useful for determining sex include the hand bones with 89-94% accuracy (Smith 1996), radius (Berrizbeitia 1989), humerus (France 1983, 1988; Holman and Bennet 1991), ribs (Iscan 1985; McCormick and Stewart 1983), femur with 85-89% accuracy (Black 1978), tibia with 85-95% accuracy (Iscan and Miller-Shaivitz 1984), metatarsals reaching up to 100% accuracy (Robling and Ubelaker 1997), and talus and calcaneus with 79-89% accuracy (Steele 1976), and many other elements as well.

Although postcranial elements prove to be better estimators of sex, since the cranium interacts with the vertebral column at the junction of the occipital condyles and the first cervical vertebra, it is important to note sex differences observed in the skull. Though male and female crania can be essentially the same in size, they vary in shape and morphology (Ferembach et al. 1980; Krogman and Iscan 1986; Bass 1995; Williams and Rogers 2006). There are certain features that are associated with males or females. For example, female crania are generally more gracile with small supraorbital ridges, while males are usually more robust and have larger mastoid processes and supraorbital ridges. Sex estimations based on visual characteristics of the cranium are sensitive to ancestry and usually result in accuracy rates between 80-90%.

In addition to morphological criteria, measurements of crania have been used to estimate sex (Parsons and Mrs. Keene 1919**;** Scott 1958; Giles and Elliot 1963; Ferembach et al. 1980; Holland 1986a; Cleaves 1993; Ousley and Jantz 1996, 2005). Most of these studies focus on frontal and height measurements of the skull, as well as incorporating the cranial base into measurements related to the upper facial structure and rest of the skull. However, some researchers recognized that these measurements were reliant upon a complete cranium, something that is not always available in anthropological settings, and therefore sought to examine the base of the skull by itself. One such study was that done by Juliet Allen Cleaves (1993). Cleaves (1993) took seven measurements on a sample of crania to investigate the sexual and racial variation of the base of the skull. The measurements taken on the base of the cranium included length and width of the foramen magnum, length of the basilar process, and length and width of the occipital condyles. Her study demonstrated that sexual variation exists at the base of the cranium; however, Cleaves' method results in only a 70% probability of correctly assigning sex to individuals based on the cranial base. With the development of FORDISC, a computer program that analyzes data on human remains, measurements from an unknown skull can be entered and tested against a large database of known individuals to provide probabilities that the individual was male or female or belonged to a particular demographic population (Ousley and Jantz 1996, 2005). Complete measurement sets are not needed for FORDISC, increasing the usefulness of craniometrics for the estimation of sex.

Research on Vertebrae

Although vertebrae have been studied since the late nineteenth to early twentieth centuries, most early research focused on comparative measurements of vertebrae without concern to possible sexual variation (Anderson 1883; Cunningham 1886; Cyriax 1920) or were of a descriptive nature (Struthers 1875; Smith 1902; Whitney 1926). However, more recently, sexual dimorphism in the vertebrae has been examined. Given that sexual variation exists at the base of the cranium, it is not surprising that Marino (1995) found sexual variation in the first cervical (C1) vertebra. Marino used a sample of 100 individuals each from the Terry and Hamann-Todd collections. Eight measurements from the superior and inferior articular facets, fovea, and vertebral foramen were used to estimate sex from C1. Marino found that sex could be correctly estimated with 75-85% accuracy for the individuals from the Terry collection and with 60-77% accuracy for individuals from the Hamann-Todd collection.

In addition to the first cervical vertebra, sexual dimorphism has also been documented on the second cervical vertebra. Wescott (2000) demonstrated sexual dimorphism in the axis in all eight measurements he included. Variation was found in the sagittal length of the vertebra, dens height, sagittal and transverse diameters of the dens, vertebral foramen length, breadth between the superior facets, and the sagittal and transverse diameters of the superior facets, with the sagittal length of the vertebra being the single most sexually dimorphic trait. Wescott was able to determine sex accurately between 76-86% of the time when using just one trait, the sagittal length. When using two to five measurements, accuracy levels for estimating sex from the axis varied between 77-90% correct.

Haugen (1994) noted sexual dimorphism from C2 to C7. Unlike Marino (1995) and Wescott (2000), four out of five of Haugen's measurements focused on the spinous process and, consequently, did not include measurements for C1. The fifth measurement was vertebral body height. All measurements were found to be sexually dimorphic, with the most notable difference being that female vertebrae are proportionally smaller than male vertebrae, and classification of sex was achieved with 69-85% accuracy, with females having slightly better sex classification than males.

Due to the importance of vertebral anatomy and physiology in surgical procedures concerning the vertebral column and spinal cord, many researchers have studied the morphology of the vertebrae for clinical application. The cervical and lumbar vertebrae have received more attention in clinical research due to the increased probability for injury from accidents or from the processes of aging. For instance, Schaffler et al. (1992) were able to demonstrate sexual variation in C2. A total of 120 specimens, equally divided between male/female and white/black groupings, from the Hamann-Todd collection were measured. A series of seven measurements relating specifically to the dens plus the length and width of the vertebral foramen were measured. Height of the dens, anterior and posterior height of the vertebral body, and minimum and maximum anteroposterior diameters of the dens were all found to be greater in men than in women. No differences between men and women were found in the minimum and maximum transverse diameters of the dens or in the transverse and sagittal diameters of the vertebral foramen.

Much of the clinical application research on the cervical vertebrae has focused on dimensions of the vertebral body, as well as the intervertebral disc. Several studies have found sex differences in cervical vertebral body heights and anteroposterior diameters, with males having larger dimensions than females for most measurements for C3-C7 (Katz et al. 1973; Liguoro et al. 1994; Lim and Wong 2003; Kwon 2004). Liguoro et al. (1994) also noted sexual variation in the anteroposterior length of C1 and anteroposterior diameter of the C2 vertebral body. Gilad and Nissan (1986) provide data collected on close to 150 cervical, C2-C7, and lumbar vertebrae, including measurements of vertebral body heights and widths; however, no females were included in the study and the male sample only included men between the ages of 20 and 38.

Because of the role of the vertebrae to enclose and protect the spinal cord, the size of the vertebral foramen has also been studied for its clinical implications, especially in the cervical spine. Conclusions as to whether or not sexual variation exists in the cervical vertebral foramina are mixed. Hashimoto and Tak (1977) and Hukuda and Kojima (2002) found no difference between males and females in the anteroposterior diameter of the vertebral foramen, although Hukuda and Kojima did report greater anteroposterior diameter and height of the vertebral body in males than in females. Payne and Spillane (1957) did report slight sex differences in anteroposterior diameter of the cervical vertebral foramina, but did not state whether or not these differences were statistically significant. Tatarek (2005) reported that sexual dimorphism was responsible for differences in anteroposterior and transverse diameters of the vertebral foramen in the cervical canal, and Lim and Wong (2004) found the anteroposterior diameter of the vertebral foramen to be significantly smaller in women than in men, except in C2 and C4. Sex differences in midsagittal and transverse diameters of the vertebral foramen and body have also been noted in the lumbar vertebral (Eisenstein 1983). Although these studies demonstrate differences in vertebral foramina size due to the importance of the spinal cord in clinical situations, the width of the foramen could have an impact on the overall length of the vertebra or on the width of the vertebral body.

MacLaughlin and Oldale (1992) examined variation in the vertebral bodies of the eleventh thoracic (T11), twelfth thoracic (T12), and first lumbar (L1) vertebrae. All three of their measurements, anterior and posterior transverse diameters and anteroposterior diameter, taken on the superior surfaces of the bodies within the vertebral rim were found to be sexually dimorphic and reliably predicted sex at 70% or above. The anterior transverse diameter was the best sex predictor, reaching levels of 87% accuracy. However, their sample came from an 18th century cemetery collection and therefore may not be applicable to modern individuals.

In a more recent study, Pastor (2005) used samples from both the Spitalfields and Terry collections to demonstrate that T12 and L1 can provide reliable means of predicting sex. Out of 12 measurements, 8 were found to vary significantly between the sexes. The most significant measurements were length of the spinous and transverse processes, articular facet width, and anteroposterior and mediolateral diameters of the vertebral body, and accuracy levels between 76-91% were achieved using one or a combination of several of these measurements. Although sex differences have been noted on certain lumbar vertebral bodies and vertebral foramina, Barry and Lively (1997) found that sex had no significant effect on the size of the superior articular facets of either L4 or L5.

Taylor and Twomey (1984) report on three different studies which all support sexual dimorphism in the vertebral column. In the first study, the length of the thoracolumbar spine was measured on 1,427 children ages 5-19, and results demonstrated that between the ages of 9½ to 12½ years growth in spine length was significantly greater in females than in males. In the second study mid-vertebral height and minimum transverse diameter of the sixth and ninth thoracic vertebrae were measured for 166 individuals from radiographs. In the third study mid-vertebral height and transverse diameter of lumbar vertebrae were measured for 105 skeletal specimens. In these last two studies, indices of height/transverse diameter were calculated and compared. Results showed that for all age groups over 8 years old, female vertebrae were relatively taller and thinner than male vertebrae (Taylor and Twomey 1984).

Taylor and Twomey's (1984) three studies indicate that sexual dimorphism in the shape of the vertebral body may be due to differential growth rates between boys and girls during puberty. In girls the pubertal growth spurt can start at approximately 8-9 years old, resulting in earlier increased growth in vertebral height than in boys. Due to testosterone effects on growth of muscle, vertebral transverse diameter in boys grows more rapidly. Though vertebral height in boys does eventually catch up and exceed that of girls, transverse diameter growth in boys still exceeds girls. These results are supported by Gilsanz et al. (1994b & 1997) studies which concluded that vertebral cross-sectional area was greater in boys than in girls and by Roche's (1972) finding that boys have greater vertebral body height growth than girls during puberty. Given the differences in vertebral body growth patterns in children, it is not surprising that even after men and women were matched for weight, age, vertebral bone density and vertebral body height, the cross-sectional area of women's vertebral bodies were found to be 25% smaller than those of men (Gilsanz et al. 1994a; Nieves et al. 2005).

Knussman and Finke (1980) demonstrated sexual variation in the spinal curvature of 103 young men and 103 young women by using a Juergens' Kypholordosometer. This method involved lining up a row of sliding horizontal rods against the spinal column profile of the back. Sexual dimorphism was found to exist in the lumbar lordosis, with women having a smaller angle of curvature in the lumbar spine and a curvature that projects more anteriorly than in men. The thoracic curvature does not angle as far back posteriorly in women as it does in men. These differences result in men having a spinal column that is more dorsally situated and women having a spinal column that is centered more closely around a vertical line drawn from the end of C7 downwards. This study demonstrated that sexual variation exists in the overall shape of the vertebral column, suggesting that variation may exist in the morphology of the vertebrae themselves.

The relationship between the curvature of the spinal column and posture of the head has also been examined. In a study of Australian aboriginal male subjects, Solow et al. (1982) found that the aboriginal cervical spinal column is shorter than previously published findings of Danish males. The curve of the aboriginal cervical column was also found to be more anteriorly inclined than in the Danish sample. Cooke and Wei (1988) undertook a similar study using a sample of 12-year-old children from southern Chinese and British Caucasian populations. For both the Chinese and British samples, the curve of the cervical vertebral column was found to be angled more forwardly in females than in males and the females also tended to hold their heads higher than the males. Though no difference in actual length of the cervical column from C2-C4 was found between males and females of either group, the relative lengths of the cervical column were greater in both female samples than in the male samples. The findings of these two studies as well as previous studies (Wood-Jones 1938; Solow and Tallgren 1976; Solow et al. 1982; Kylamarkula and Huggare 1985; Fjellvang and Solow 1986; Huggare 1986) indicate that there may be both physical and cultural factors influencing sexual variation in the posture of the head, which may have an effect on the morphology of the vertebrae.

Throughout life the skeleton undergoes change, either growth or degeneration, and differences in rates of these processes have been noted between males and females. Even when using the most reliable element for sexing, it has been demonstrated that the same standards cannot be used for aging the os pubis of males and females. As Gilbert (1973) established, using male standards for aging female os pubis bones will result in inaccurate age estimations. Sexual variation in the aging of the vertebrae has also been described. As discussed previously, there are differential vertebral growth rates for boys and girls, which may be partly responsible for possible sexual dimorphism in the vertebral column (Roche 1972; Taylor and Twomey 1984; Gilsanz et al. 1994b & 1997). Ericksen (1976, 1978a, 1978b) studied the lumbar vertebrae for age-related changes and found that the overall shape of the vertebral body changes. With an increase in age comes an increase in the transverse diameters of the endplates and minimum transverse diameter as well as a broadening of the body. A decrease in posterior body height relative to anterior height is seen in males, making the vertebrae more “wedge-shaped” with age. Anterior height of the body also decreases, which, when combined with an increase in transverse breadth, makes the lumbar vertebrae relatively lower and broader.

In addition to the changes discussed by Ericksen (1976, 1978a, 1978b), the most common indicator of age sited in the vertebrae is lipping around the articular surfaces, also known as osteophytes (Stewart 1958; Krogman and Iscan 1986). Although caused more by injury to the joints or ligaments associated with the vertebrae rather than by aging alone, osteophyte development does increase with age (Jackson 1978). Even though the frequency of osteophytes increases as a person ages, Stewart (1958) found that they were unreliable for predicting age. Snodgrass (2004) noted that osteophyte formation follows a general pattern both in males and females, although greater variation is seen in females. Despite Snodgrass's findings, evidence of differential aging between males and females suggests that care should be taken when examining vertebrae to account for differences in age.

Stature estimation is also important in anthropological and forensic settings. The most popular bones for determining stature are the long bones of the legs (Trotter and Gleser 1952; Krogman and Iscan 1986). However, the vertebral column makes up a substantial percentage of a person's height as well and therefore has been studied to some extent for stature estimation. Dwight (1894) established that the spinal column could be reliably used for stature estimation by taking a measurement of the entire column, but his method required an intact spine and not individual vertebrae. Due to the need to provide stature estimations in forensic cases, Jason and Taylor (1995) developed a more reliable method to estimate stature from an intact vertebral column that could be measured during an autopsy.

In many situations an intact spinal column is not present so Fully and Pineau (1960) measured a large sample of European male vertebrae individually and developed stature equations as well as a list of the percentages of each vertebra to the total length of the vertebral column (Tibbetts 1981). Tibbetts (1981) continued this research by sampling 100 black male and 100 black female sets of vertebrae and establishing regression formulae for estimating stature. However, only about 40% of the variation seen in stature in this sample was attributed to sex. Therefore, the standard errors were much greater than those for stature equations based on long bones, indicating that though the vertebrae are valuable in determining stature, long bones are the preferable tool for stature estimation.

Developmental Anatomy

Since dimensions of the vertebrae are to be considered in this study, it is necessary to first consider the development of the vertebral column. The eventual shape and morphology of the adult vertebrae is at least partially defined by the process of formation of the vertebral column. The vertebral column grows in stages throughout the embryonic and fetal phases, as well as after birth. Starting about the third week of development, the notochord appears, which will provide the foundation for the vertebral column. At this point the notochord is unsegmented, rod-like in shape and extends the full length of the future vertebral column. Mesoderm surrounds the notochord and separates it from the neural tube. Eventually, the notochord will be completely enveloped by the developing vertebrae and will only exist in the intervertebral discs (Gray 1973; Bailey 1974; Verbout 1985).

About the twentieth day of embryonic development, the bilateral segmentation of the paraxial mesoderm, on the lateral sides of the notochord, begins in the occipital region and continues caudally. These cubical masses are called somites and approximately 44 pairs develop (Gray 1973). Each somite develops into a dermatome, myotome, and sclerotome. The dermatome will eventually form dermis tissue, the myotome will become skeletal muscle, and the sclerotome will form into vertebrae. As the cells of the sclerotomes migrate towards the notochord, the perichordal sheath forms a septum dividing the provertebral bodies into right and left halves. This column of sclerotomes consists of alternating dense and less dense areas proceeding downward (Bailey 1974; Sherk and Parke 1983; Verbout 1985).

Starting between the fifth and sixth weeks, resegmentation of the sclerotomes begins with the left and right halves fusing across the midline. During the fusion process, the notochord is integrated into the developing vertebrae. The less dense areas of the sclerotomes are characterized by the presence of mesenchymal cells. These areas give rise to the intervertebral discs. At the same time, the caudal halves of the sclerotomes join with the cranial half of the adjacent sclerotome to form the primordial vertebral bodies. Cells from this primitive vertebral body move dorsally, surrounding the developing spinal cord, to form the vertebral arch and ventrally to form the ribs or costal processes (Sherk and Parke 1983; Verbout 1985). The basic outline of the vertebral column is laid out at this time and chondrogenesis and osteogenesis now begins.

Chondrogenesis is the construction of a cartilaginous cell matrix in place of the mesenchymal cells of the primitive vertebrae. This process begins in two separate centers in each vertebral body. The chondrification centers on either side of the midline generally unite rapidly and force the notochordal tissue out of the vertebral body and into the intervertebral disc space, where it remains and forms the nucleus pulposus. Chondrification centers also exist in the vertebral arch and each costal process; these centers also unite and eventually also merge with the vertebral body by the eighth week of development (Bailey 1974; Sherk and Parke 1983; Verbout 1985). The primitive vertebrae are now completely composed of cartilage and ready for osteogenesis to take place.

Chondrification and ossification of the vertebral column follows a general pattern for each vertebra, but the first and second cervical vertebrae follow slightly different outlines. The first cervical vertebra does not form a true body. The caudal half of the C1 somite fuses with the cranial half of the C2 somite to form the odontoid process of the second cervical vertebra. The odontoid process is incorporated with the body of C2. Since the body of C1 has been caudally displaced, the anterior arch is formed from the ventral extension of a dense band of tissue, called the hypochordal bow. Although the hypochordal bow occurs at other vertebrae, it is not as pronounced as the vertebrae move more caudally, and eventually the hypochordal bow gives rise to the anterior longitudinal ligament (Bailey 1974; Sherk and Parke 1983; Verbout 1985).

The first cervical vertebra undergoes ossification from two primary centers. At about the seventh to eighth week of development, an ossification center develops in each neural arch. By birth, ossification has spread, but the neural arches are only connected by cartilage both ventrally and dorsally. The second cervical vertebra has five primary ossification centers: one in the vertebral body, one in each side of the neural arch, and two in the odontoid process (Gray 1973; Bailey 1974; Sherk and Parke 1983). The neural arches of C2 are also not fused together by the time of birth. The rest of the vertebrae have three ossification centers each, the same as the first three for C2: one in the vertebral body and one in each neural arch. Ossification of the vertebral bodies starts in the lower thoracic region about the eighth week of development and commences up and down the column (Gray 1973). At the time of birth, the vertebrae are not fully ossified and three separate components exist: the body itself and each neural arch. Each part is still joined by cartilage, forming synchondroses.

Ossification of the vertebral column continues to follow the cartilaginous precursor, though sometimes secondary ossification centers are formed. The posterior arch of the first cervical vertebra is completed by the third or fourth year after birth. A secondary ossification center develops in the anterior arch toward the end of the first year and fuses with the lateral masses between the sixth to eighth years. The odontoid process of C2 begins to ossify with the body starting about age four and is complete by age seven (Gray 1973; Bailey 1974; Verbout 1985). During the first year after birth, ossification in the neural arches of the vertebrae continues posteriorly, eventually joining first in the lumbar vertebrae and then proceeding upward to the thoracic and cervical vertebrae. Beginning about age three, the vertebral bodies of the upper cervical region unite with the neural arches on either side. This process of union continues down the vertebral column, with the lower lumbar vertebral bodies fusing to the arches by age six (Gray 1973).

Secondary ossification centers also develop at the margins of the vertebral bodies. Rings of hard cortical bone form around the bodies, while the unossified inner regions serve as an anchor for the intervertebral discs. Debate exists as the exactly when these rings form and fuse to the primary ossification centers, but most put the beginning of these secondary centers around 15 years of age and fusion by 25 years of age (Bailey 1974; Buikstra and Gordon 1980; Sherk and Parke 1983). The tips of spinous and transverse processes are also sites of secondary ossification around age 16. Usually only one secondary center occurs at the ends of the spinous processes, but in the cervical vertebrae two secondary centers can occur, resulting in bifid spinous processes (Bailey 1974; Sherk and Parke 1983; Verbout 1985).

Morphology

Before an examination of the vertebral column is to be initiated, a more in depth understanding of the morphology of the vertebrae is needed. The majority of the vertebrae, from the third cervical to the fifth lumbar (C3-L5), exhibit similar morphology whereas the first and second cervical vertebrae are unique in their structures. The "typical" vertebral morphology varies slightly from cervical to thoracic to lumbar vertebrae, but can still be generalized as having several main features: vertebral body, neural arch, transverse processes, spinous process, and articular facets (see Fig. 1).

The "typical" vertebra can be divided into an anterior body and posterior vertebral arch. The body is basically cylindrical in shape and is comprised of cancellous bone with a thin covering of cortical bone. There is a raised ridge of bone, the vertebral rim, that outlines both the superior and inferior surfaces of the body. Moving down the vertebral column, the size of the body increases to support the increasing weight placed on the vertebrae. The cervical vertebral body is wider from side to side than anterior to posterior. Superiorly, the sides of the body are taller than the center, resulting in a saddle-shaped appearance. Consequently, the inferior surface is convex, except in the seventh cervical, which is flat on the inferior surface of the body. Also, the anterior border of the inferior surface projects more caudally than the posterior border and overlaps the vertebra located below it. The thoracic and lumbar vertebral bodies have flat surfaces (Gray 1973; White and Panjabi 1978; Bass 1995).

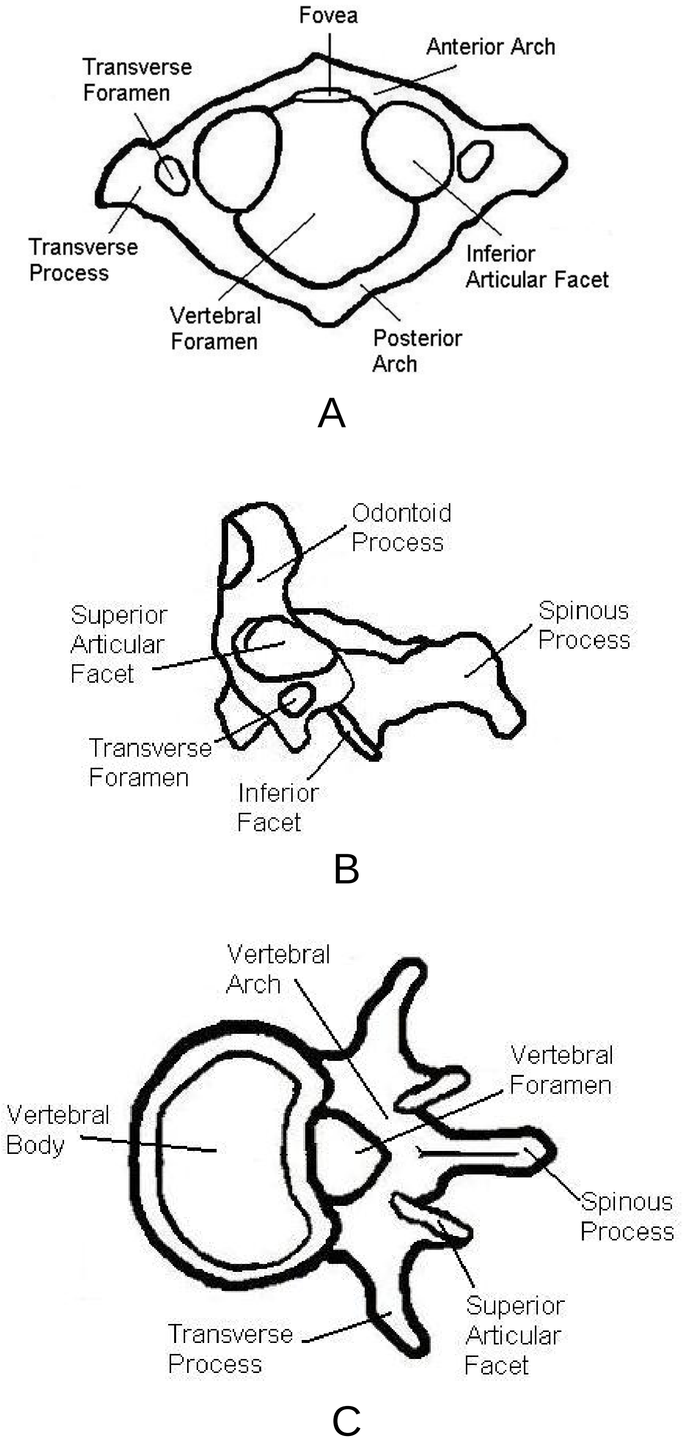

FIG. 1—Line drawing of the first cervical vertebra from an inferior view (A), the second cervical vertebra from a lateral view (B), and a lumbar vertebra from a superior view (C) illustrating morphology of the vertebrae.

The neural, or vertebral, arch attaches to the body posteriorly to form a triangular hole, the vertebral foramen, which encloses and protects the spinal cord. Projecting laterally from the arch on each side are the transverse processes. In the cervical vertebrae the transverse processes are small and have transverse foramina, which allow for the passage of blood vessels and nerves. The transverse processes in the thoracic and lumbar vertebrae are much larger and project further posteriorly than in the cervical (Gray 1973; White and Panjabi 1978; Bass 1995).

The posterior projection of the vertebral arch is the spinous process, where muscles of the neck attach. The cervical spinous processes are generally bifid, except for C7, and often slope downwards to some degree. The seventh cervical has a very long spinous process that is nearly horizontal and ends in a large tubercle. The thoracic spinous processes vary from the first thoracic (T1) to the twelfth thoracic (T12) vertebrae. Starting with T1 the processes most resemble that of C7, but start to project further downward continuing down the spine. The spinous processes of the 4 or 5 middle thoracic vertebrae project obliquely and overlap one another. In the bottom portion of the thoracic region, the spinous processes project downward less and become shorter. The lumbar spinous processes project close to horizontal, are thick, and are more squarish in shape (Gray 1973; White and Panjabi 1978; Bass 1995).

All vertebrae have pairs of superior and inferior articular facets that are roughly ovoid or circular in shape. The superior articular facets are located on the superior aspect of the vertebral arch next to the transverse processes and point posteriorly. The inferior articular facets are located on the inferior side of the vertebral arch almost directly below the superior facets and point anteriorly. The superior articular facets on the lumbar vertebrae are concave and face posterior-medially. In the twelfth thoracic and the lumbar vertebrae, the inferior facets are convex and face anterior-laterally. In addition to the superior and inferior facets, the thoracic vertebrae have costal articular facets on the sides of the body and transverse processes for articulation with the ribs (Gray 1973; White and Panjabi 1978; Bass 1995).

The first and second cervical vertebrae display some of the "typical" morphological features, but are unique in their structure. The first cervical, known as the atlas since it is responsible for holding up the head, has no body. During development the precursor of the body fuses with that of the second cervical vertebra. Instead of a body, the atlas has an anterior and posterior arch, which forms a ring with the vertebral foramen on the inside. On the interior (posterior) surface of the anterior arch is a rounded, smooth facet, called the fovea, for articulation with the second cervical vertebra. The atlas also lacks a spinous process; instead, a posterior tubercle exists at the midpoint of the posterior arch. Lateral masses form the sides of the ring and provide support for the articular facets. The superior articular facets are large, oval, concave, and face superiorly to allow articulation with the occipital condyles on the base of the skull. The inferior articular facets are circular and flat or slightly concave and point downward for articulation with C2. The atlas also displays the small, lateral transverse processes and transverse foramina characteristic of other cervical vertebrae (Gray 1973; White and Panjabi 1978; Bass 1995).

The second cervical vertebra is called the axis because it allows the atlas, and subsequently the skull, to turn from side to side. The feature that allows this movement is the prominent odontoid process, commonly called the dens. The dens is formed from the joining of the precursors of the C1 body to that of the C2 body. There is a smooth facet on the anterior surface of the dens that articulates with the fovea of the atlas, which allows for the turning movement of the head. The dens takes the place of the superior surface of the body. The superior articular facets are large, circular, sometimes slightly convex, face superiorly, and are located next to the dens, at the junction of the body and ventral arch. The inferior facets are similar to those of the rest of the cervical vertebrae (Gray 1973; White and Panjabi 1978; Bass 1995).

Statement of Purpose

Although there have been numerous studies examining differences in various aspects of the vertebral column, few studies focus specifically on developing formulae that may be useful in the estimation of sex from the vertebrae. Such studies have demonstrated that the cervical and T11 through L1 vertebrae can be useful in determining sex with a reasonable level of accuracy (MacLaughlin and Oldale 1992; Haugen 1994; Marino 1995; Wescott 2000; Pastor 2005). Both the results of these studies and evidence that sexual dimorphism exists in the cranial base, ribs, and sacrum suggest that sexual variation may exist throughout the entire vertebral column. Though a visual examination may not reveal sexual dimorphism in the vertebral column, metric analyses may be able to demonstrate any possible variation that may prove useful in determining sex. The primary purpose of this study is to examine possible sexual dimorphism in the vertebral column by conducting metric and statistical analyses on each of the 24 vertebrae and secondly, if sexual variation is found to exist, develop formulae by which sex can be estimated on an isolated vertebra from an unknown individual. The effects of age on the vertebrae will also be discussed as well as the potential usefulness that being able to determine sex from the vertebral column may allow. The null hypothesis for this study is that vertebral measurements have no relationship with sex and that age has no interaction with sex for these measurements. The test hypothesis is that vertebral dimensions are affected by sex and that there is an interaction between age and sex.

Materials and Methods

In this study, a total of 119 individuals from the University of Tennessee William M. Bass Skeletal Collection were used. The William M. Bass Collection consists of over 500 individuals that represent a modern population. Most of these individuals were donated to the collection and, for the majority, sex, age, and ancestry are known. Due to the small representation of African-American individuals in the Bass Collection, only individuals of European ancestry were selected for this study. Since the collection consists overwhelmingly of older white males and since effects of aging are well known in the vertebral column (Stewart 1958; Ericksen 1976,1978a, 1978b), equal numbers of males and females were selected randomly and matched for age groups. A total of 120 individuals were measured ranging in ages from 18-86 (Table 1); however, one female was of unknown age and therefore was not used in the study since effects of age are being considered.

Data Collection

All 24 vertebrae from each individual were measured for this study. However, in many cases one or more vertebrae were either missing, fused, or broken. In these instances, any measurements that could be taken were recorded and used in the statistical analyses when possible. This resulted in few of the 119 individuals having complete measurements for all 24 vertebrae. Standard groupings of vertebrae were also analyzed;

Table 1. Composition of the Bass Collection sample.

	N	Mean Age	Std Dev	Max. Age	Min. Age
Male	60	55.7	11.79	86	25
Female	59	56.5	11.35	85	18-25
Total	119	56.1	11.58	86	18

i.e., cervical, excluding C1 and C2, thoracic, lumbar, and the entire vertebral column from C3 to L5. The exclusion of one vertebra or measurement did not exclude an individual. If a vertebra from an individual was missing or excluded, then that individual would be excluded from statistical analyses for that vertebra. This resulted in different sample sizes for each vertebra and vertebral grouping (Table 2). The total possible sample size for each individual vertebra for males was 60 and for females 59. The maximum sample size possible for the C3-C7 grouping was 300 for males and 295 for females; for the thoracic grouping it was 720 for males and 708 for females; for the lumbar grouping it was the same as for the C3-C7, 300 and 295; and the total possible sample size for C3-L5 was 1320 for males and 1298 for females. No vertebra or vertebral grouping was represented by all individuals (Table 2), and each measurement for each vertebra and vertebral grouping also had different sample sizes (see A1-A28).

Table 2. Sample size per vertebra and vertebral grouping.

Vertebra or Vertebral Grouping	Maximum Number		Vertebra or Vertebral Grouping	Maximum Number	
	Male	Female		Male	Female
C1	50	53	T8	55	50
C2	52	55	T9	51	48
C3	42	53	T10	54	49
C4	39	50	T11	52	50
C5	41	42	T12	56	52
C6	44	46	L1	53	54
C7	55	56	L2	56	55
T1	59	57	L3	56	52
T2	57	55	L4	57	53
T3	59	53	L5	45	42
T4	58	52	C3-C7	221	247
T5	58	53	Thoracic	672	614
T6	58	48	Lumbar	267	256
T7	55	47	C3-L5	1160	1117

A series of nine measurements were taken on all twenty-four vertebrae using a Mitutoyo digital sliding calipers and measuring to the nearest millimeter. Due to structural differences in the first and second cervical vertebrae, not all measurements could be recorded on these two elements. However, one additional measurement was recorded for the first cervical vertebra and two additional measurements were recorded on the second cervical vertebra, bringing the total number of measurements for these two elements to 10 and 11, respectively. There were also four measurements that were taken on all but the first and second cervical vertebrae, bringing the total to 13 measurements taken for the third cervical to the fifth lumbar vertebrae. For bilateral structures, the left side was measured unless it was deformed or broken, in which case the right side was used if possible. In some instances measurements could not be recorded due to the presence of osteophytes. If osteophytes occurred on the left facets, then measurements from the right side were used if possible, although measurements using both sides, such as facet breadth, could usually still not be taken. If osteophytes occurred on the vertebral body or spinous process, all attempts were made to make an accurate recording. For example, if a small growth of bone was present at the anterior midline of the body, the calipers could be moved just slightly away from the midline to achieve an accurate measurement for either the sagittal length of the vertebral body (SLV) or the maximum sagittal length (XSL). However, if the osteophyte was too large and interfered with collecting data, then that measurement would not be recorded.

For comparative purposes, measurements described in previous literature were used when possible. Marino (1995) described eight measurements that were recorded on the first cervical vertebra. Since Marino took measurements on both the left and right sides, six of Marino's measurements were used in this study, although the abbreviations used to represent several of the measurements are not the same. Wescott (2000) defined eight measurements that he recorded on the second cervical vertebra. Several of these measurements were the same as Marino's measurements. Seven of Wescott's measurements were used in this study. Martin and Saller (1957) also defined several of the measurements used in this study: sagittal diameter of the vertebral foramen, middle sagittal and transverse diameters, and the anterior and posterior heights of the vertebral body.

There were a total of 16 different measurements taken on the vertebrae. Not all measurements were taken on each vertebra. Table 3 defines the measurements included in this study and states for which vertebrae each measurement was taken while Figure 2 illustrates each measurement.

Statistical Procedure

All statistical analyses were performed using the SAS 9.1 statistical programming software. Both MANOVA and discriminant function analysis were run for each vertebra and vertebral grouping to test the null hypothesis that sex has no effect on the dimensions of the vertebrae. The MANOVA procedure examines the relationship between the independent variables (e.g. sex or age) against multiple dependent variables (e.g. measurements). For this study, the MANOVA procedure tested for significance by the independent variables sex, age, and sex*age. The sex*age variable measures the possible interaction between sex and age. First, the overall significance of sex, age, and sex*age for each vertebra or vertebral grouping using all measurements for that vertebra or group was examined. If sex, age or sex*age was found to be significant for a vertebra

Table 3. Definition of Vertebral Measurements*

Measurement	Definition	Vertebrae Measurements Recorded For
WFV – maximum width of the fovea	Maximum width of the fovea measured parallel to the sagittal plane	C1
XDH – maximum height of the dens	Height from the most superior point of the dens to the most inferior point on the body	C2
XDW – maximum width of the dens	Maximum sagittal width of the dens taken at articular surface.	C2
LSF – maximum length of superior facet	Maximum anteroposterior (or superior-inferior as move down the vertebral column) diameter of the superior articular facet	C1 – L5
WSF – maximum width of superior facet	Maximum mediolateral width of the superior articular facet	C1 – L5
LIF – maximum length of inferior facet	Maximum anteroposterior (or superior-inferior as move down the vertebral column) diameter of the inferior articular facet	C1 – L5
WIF – maximum width of inferior facet	Maximum mediolateral width of the superior articular facet	C1 – L5
SFB – superior facet breadth	Maximum breadth from most lateral edges of superior articular facets	C1 – L5
IFB – inferior facet breadth	Maximum breadth from most lateral edges of inferior articular facets	C1 – L5
XHF – maximum height of facets	Maximum height of articular facets from most superior edge of superior facet to most inferior edge on inferior facet	C1 – L5
LVF – length of vertebral foramen	Maximum sagittal length of vertebral foramen from most anterior edge of neural arch to most posterior edge of vertebral body	C1 – L5
XSL – maximum sagittal length of vertebra	Maximum sagittal length from most anterior edge of vertebral body to most posterior edge of spinous process	C1 – L5
SLV – sagittal length of vertebral body	Maximum sagittal length from the anterior edge to the posterior edge of the vertebral body	C3 – L5

Table 3 cont'd. Definition of Vertebral Measurements*

TLV – transverse length of vertebral body	Maximum transverse length from the lateral edges of the vertebral body	C3 – L5
XHP – maximum height of posterior vertebral body	Maximum height from the most superior edge to the most inferior edge of the posterior border of the vertebral body	C3 – L5
XHA – maximum height of anterior vertebral body	Maximum height from the most superior edge to the most inferior edge of the anterior border of the vertebral body	C3 – L5

*All measurements except XHF were previously defined by either Martin and Saller (1957), Marino (1995), or Wescott (2000), though exact terminology and abbreviations may differ slightly.

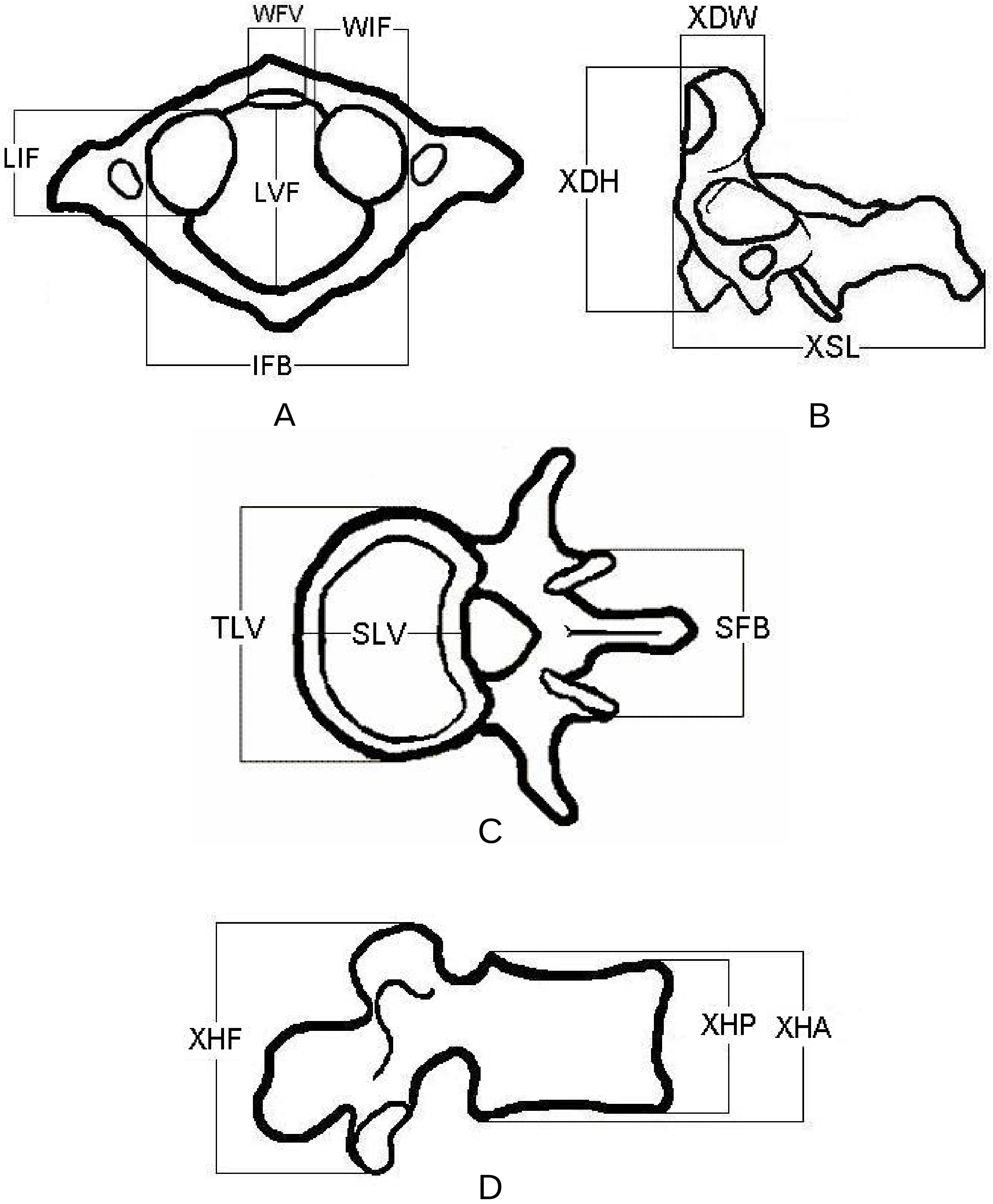

FIG. 2—Line drawing of the first cervical vertebra from an inferior view (A), the second cervical vertebra from a lateral view (B), and a lumbar vertebra from a superior (C) and lateral (D) view illustrating measurements used in this study.

or vertebral grouping as a whole, then further analyses were performed to determine which individual measurements were significant for the independent variables for each vertebra and grouping. If sex*age was not significant for a vertebra or vertebral grouping as a whole, then the individual measurements for that vertebra or grouping were not analyzed according to sex*age. If a variable was found to be not significant for sex for sex*age, meaning that there is an effect between age and sex for that measurement, then the variable was removed from further statistical analysis. If a measurement was found to be significant for age, it was not removed from further analysis since sexual dimorphism is the main effect being investigated. Discriminant function analysis is a method by which to classify individuals into two or more defined populations. In this case, discriminant function analysis was used to classify individuals from the sample as male or female. First a stepwise procedure was conducted to select a subset of variables that were the most discriminating for each vertebra or vertebral grouping. Discriminant analysis was then used for the variables selected in the stepwise procedure to estimate sex for each individual using a cross-validation procedure. The cross-validation procedure classifies the sex each individual based on a function using all cases except the individual being considered, this keeps the individual under consideration from influencing the discriminant analysis used to classify it.

Results

Means and standard deviations of all measurements for each vertebra and vertebral grouping were calculated (see tables in appendix A1-A28).

The MANOVA procedure showed that sexual dimorphism does exist in the vertebral column. All measurements displayed sexual dimorphism for at least one vertebra or vertebral grouping. Most variables also exhibited significant effects due to age for one or more vertebrae; however, few dimensions showed a strong interaction effect between sex and age. The results for each vertebra and vertebral grouping are described below.

Results per Vertebra

For the first cervical vertebra, all measurements demonstrated strong significance for sex and only one measurement, superior facet breadth (SFB), was significant for age. However, the overall test of sex*age on C1 did not show any significance; therefore, no variables were excluded from the stepwise procedure. The inferior facet breadth (IFB) proved to be the most discriminating measure for C1 with an R-square value of 0.4702, followed by the maximum sagittal length (XSL) with an R-square value of 0.2334. This means that these two measurements account for 47% and 23%, respectively, of the total variation of the model attributed to sex, and including the width of the superior facet (WSF) would only account for an additional 3% for the variation. Alone IFB predicted sex accurately 84.1% of the time. IFB and XSL proved to be the best equation with 90.4% of males and 94.4% of females being correctly classified and a total accuracy of 92.4% (see B1, C1, D1).

Length of the inferior facet (LIF) is the only measurement that was not significant for sex for the second cervical vertebra. Both SFB and XSL showed significance for age, but, like the first cervical, the overall test that age interacts with sex was not significant. Stepwise analysis showed that XSL accounted for the highest percentage of variance with an R-square value of 0.5997 and correctly classified males 92.4% and females 85.7% of the time. SFB accounted for an additional 15% of the variance and, though the addition of SFB only marginally increased sexing accuracy for males, to 92.5%, accuracy for females increased to some extent to 89.3%. Since XSL and SFB together accounted for 75% of the variation in the model, the addition of the length of the superior facet (LSF), with an R-square of 0.0523, did not significantly increase classification accuracy for C2 (see B2, C2, D2).

Sex was found to be significant for all measurements for the third cervical vertebrae except for LSF. Age was significant for both LIF and XSL. The interaction effect of sex and age was not found to be significant for C3 as a whole, so only LSF was excluded from further analysis. Together the first three variables selected by stepwise analysis, XSL, maximum height of the posterior vertebral body (XHP), and transverse length of the vertebral body (TLV), had an R-square value of 0.8135 and using one, two or all three measurements reached accuracy levels of correctly sexing individuals between 82.6% and 89.7%. However, adding length of the vertebral foramen (LVF) and sagittal length of the vertebral body (SLV) increased the R-square value to 0.9838 and the discriminant function equation that included all five of these variables reached 97.6% accuracy for males and 88.9% accuracy for females. Although the addition of maximum height of the anterior vertebral body (XHA) decreases the total percent accuracy from the previous equation using only five variables, the percent of males and females correctly classified is much closer, 92.9% and 90.7% respectively (see B3, C3, D3).

The fourth cervical vertebra also had one variable that was not significant for sex, LVF and half of the measurements demonstrated significance for age. Although the overall test of sex*age for C4 was significant, no individual measurements displayed significance for the relationship between age and sex. XHP accounted for nearly half of all the variation in the model and when used by itself XHP reached a total accuracy of 84%. However, females were correctly classified at a much higher rate than males, 94.4% and 73.5%, respectively. With the addition of IFB and XSL, accuracy rates for males and females reached 87.5% and 88%; the addition of WSF did not change the accuracy rates for either males or females (see B4, C4, D4).

All measurements for the fifth cervical vertebra except width of the inferior facet (WIF) and LVF had p-values below the alpha level of 0.05, and therefore rejected the null hypothesis that sex has no effect on vertebral dimensions. WSF, XSL, and SLV were all significant for age, but the null hypothesis that age has no interaction with sex was not rejected for the vertebrae as a whole. The combination of XSL, XHA, and IFB explains 75% of the variation in the model and correctly sexes both males and females at 88.1%. The addition of the last variable selected in the stepwise analysis, WSF, actually decreases the classification accuracy to 85.7% for males, making the total classification rate 86.9% (see B5, C5, D5).

Three measurements did not illustrate significance for sex in the sixth cervical vertebra: LSF, LIF, and LVF. While LIF and SLV both showed significance for age, no significance was found for the interaction between sex and age for C6. Stepwise analysis showed that IFB and XSL were the most discriminating measurements for C6 with R-square values of 0.4356 and 0.2176, respectively. The discriminant function equation utilizing these two variables also proved to be the most accurate with 86.7% of males and 87.5% of females being sexed correctly. Although the total accuracy level for the equation that also included both SLV and XHA was actually higher than that for IFB and XSL together, only the rate for females increased, to 91.5%, while the percentage accuracy for males decreased marginally (see B6, C6, D6).

The p-values for all variables for the seventh cervical vertebra for the effect of sex were below the alpha level of 0.05, although LVF was just under at 0.0497, but LVF was not selected under the stepwise procedure as having a strong discriminating ability. Significant values for the effect of age were displayed for WSF, XSL, and SLV. The overall test for an interaction between sex and age was not significant. XSL was shown to be the best single measurement, accounting for 52% of the variation and reaching a total accuracy of 86.7% of individuals sexed correctly. The highest accuracy was for the discriminant function that also included SFB, WSF, LIF, and XHP, with males correctly classified 92.7% and females 96.4% of the time. The addition of maximum height of the facets (XHF), which only accounted for 3% of the variation of the model, did not increase the accuracy of individuals correctly sexed (see B7, C7, D7).

All measurements for the first thoracic vertebra were significant for sex and only XSL and SLV were significant for age. Also, T1 failed to show significance for the interaction between sex and age. Once again, XSL was the single best discriminating variable and accounted for over 50% of the variation. The discriminant function equation using just XSL classified 86.7% of males and 91.4% of females correctly. These accuracy levels increased to 91.5% for males and 91.2% for females by adding IFB and XHP to the equation (see B8, C8, D8).

The second thoracic vertebra also demonstrated significant effects for sex for all variables, only significant effects for age for XSL and SLV, and no significance for the relationship between sex and age. The combined R-square value for XSL, SFB, and XHF was 0.8412 and the last three variables selected under the stepwise procedure only added 0.1239 to the R-square value. The combination of XSL, SFB, and XHF for T2 produced classification accuracy levels of 89.7% for males and 89.5% for females and the subsequent addition of IFB, WSF, and LSF only increased the accuracy of classification minimally (see B9, C9, D9).

The null hypothesis that sex has no effect was rejected for all measurements for the third thoracic vertebra. The hypothesis that age has no effect was rejected for IFB, XHF, XSL, and SLV, but T3 did not demonstrate significance for the relationship between age and sex and therefore no variables were excluded from the stepwise procedure. XSL and SFB were the two most discriminating dimensions, accounting for over 70% of the sexual variation and the discriminate function for these two variables classified 88.1% of males and 90.7% of females correctly, with a total accuracy of 89.4%. Adding XHA to the equation did not change the accuracy rates and subsequently adding TLV, WSF, and LIF actually decreased classification levels slightly (see B10, C10, D10).

LVF is the only variable for which sex is not significant for the fourth thoracic vertebra. Several of the measurements do exhibit significance for age, but the hypothesis that age has an interaction effect on sex for T4 was rejected. Stepwise analysis showed that XSL is again the single most discriminating variable with an R-square value of 0.4328. The total classification rate for the equation using just XSL is 85.9% while the total classification rate for the rest of the discriminant equations ranged from 83.1% to 87.4%, with the most accurate equation being that which includes XSL, TLV, XHF, SFB, and SLV (see B11, C11, D11).

While IFB was the only measurement that did not display significant differences attributed to sex, WSF, SFB, IFB, XHF, XSL, and SLV all showed significant effects due to age. The overall test of interaction between sex and age did exhibit significance, but only IFB and XHP demonstrated any significance due to the interaction of sex and age when the dimensions were analyzed independently, so these two variables were the only to be excluded from stepwise analysis. XSL explains 40% of the variation in the model and the inclusion of XHF, SFB, and WSF accounts for an additional 33%, bringing the total for these four variables to 73%. The discriminant function equation utilizing these four dimensions correctly classified 84.5% of males and 86.8% of females. The addition of TLV, which only accounts for 2% of the variation, has the same total classification rate as for the equation with four variables, but the percent of males classified correctly decreases while that of females increases, which results in a larger range between their accuracy levels (see B12, C12, D12).

For the sixth thoracic vertebra, all measurements except LVF were significant for sex and only WSF, XHF, XSL, and SLV were significant for age. There was no significance for the overall interaction between sex and age. Stepwise analysis selected a subset of three variables, IFB, SLV, and XHA, which together have an R-square value of 0.6809. The classification rates of the discriminant functions for males ranges between

74.6% and 86.4% while for females classification rates are between 76.9% and 86.3% (see B13, C13, D13).

Only LIF and LVF did not exhibit significant differences due to sex in the seventh thoracic vertebra, while XSL and SLV demonstrated significance due to age. Again, the overall test for an interaction effect between sex and age was not significant. TLV proved to be the most discriminating variable with an R-square value of 0.3949, followed by IFB with a value of 0.1291. Together these variables classified 80% of males and 84% of females correctly. These percentages were increased to 85.5% and 87.2% when XHP and XSL were added to the discriminant function (see B14, C14, D14).

The dimensions of the eighth thoracic vertebra were all significant for sex except for LSF and LVF. The only dimensions that had significant differences due to age were WSF and SLV. Since T8 did not demonstrate any differences due to the interaction effect of sex and age, only LSF and LVF were excluded from stepwise analysis. XSL and XHP together explain over half of the variation of the model with an R-square of 0.5193 and correctly sexed 82.5% of the sample individuals. Although adding IFB and WIF only increases the R-square value to 0.5712, the total number of males and females correctly classified increases to 85.9% (see B15, C15, D15).

As with T8, both LSF and LVF were the only measurements not to exhibit significance due to sex. The p-values for all variables were above 0.05, so the null hypothesis that age has no effect was not rejected, neither was the hypothesis that sex and age have no interaction for all measurements inclusively. The stepwise procedure found XSL and SFB to be the most discriminating variables for sex determination and their discriminant function equation accurately sexed 84.6% of males and 92% of females.

XHA only accounts for an additional 2% of the variation and the inclusion of XHA to the discriminant function analysis actually decreased classification accuracy for both males and females from the equation for just XSL and SFB alone (see B16, C16, D16).

Once again, the only two dimensions not significant for sex in the tenth thoracic vertebra are LSF and LVF. A few variables showed significance for age, but there was no significance for the relationship between sex and age for T10. The combined R-square value for XSL and IFB was 0.6927 and together they classified a total of 87.5% of individuals correctly, but the percentage of males properly classified was much lower at 81.1% than females at 93.9%. Though LIF only increased the R-square value by 0.044, its addition to the discriminant function raised the percentage of males correctly classified to 84.9% and the total to 88.6% (see B17, C17, D17).

For the eleventh thoracic vertebra, only one measurement was excluded from stepwise analysis: LVF. LVF was the only variable to not show significant sex differences and, though several variables did illustrate significant differences due to age, there was no significant difference for the combined test for an effect between sex and age. XSL and IFB are the best discriminating variables for T11 and together explain 70% of the sexual variation. The discriminant function for XSL and IFB correctly sexed 87% of males and 90% of females. The addition of SFB increases the female classification to 98%, but decreases the male classification to 83%. The addition of other variables only offers small increases in classification accuracy (see B18, C18, D18).

All measurements for the twelfth thoracic vertebra were significant for sex except for IFB and LVF and all but XSL, SLV, and TLV were not significant for age. Overall, T12 did not demonstrate any significance for a relationship between sex and age.

Stepwise analysis resulted in TLV and SFB being the two most important discriminating variables for sex. The discriminant function for these two variables resulted in 88.4% of the sample individuals being correctly classified. The addition of XSL and WIF raises the percent of females classified correctly, but decreases the percentage of males correctly classified, resulting in slightly lower total accuracy rates (see B19, C19, D19).

For the first lumbar vertebra, SFB and LVF were found to not be significant for sex while all other variables were significant, although the p-value for LIF was 0.0498. While XSL, SLV, and TLV showed significance for age, the overall test for significance for the relationship between of sex and age was not rejected. The stepwise procedure only listed two variables, TLV and SLV, as being statistically significant discriminators of sex for L1. Though TLV has a high R-square value of 0.5235 and SLV has a low value of 0.046, the best discriminant equation is that which uses both variables, which classifies males at 81.5% and females at 87.5% (see B20, C20, D20).

Though several variables demonstrate significant differences for age for the second lumbar vertebra, LVF is the only variable that exhibits no significant differences for sex and since there is no significance for the interaction of sex and age, it is therefore the only variable not included in the stepwise analysis. TLV and XSL combined explain 55% of the variation for sex for L2 and reach an accuracy level of 82.1% for males and 83.6% for females. The inclusion of additional variables in the discriminant analysis leads to a high of 85.7% accuracy for males and 87.3% for females (see B21, C21, D21).

Most of the measurements for the third lumbar vertebra show significant values for the effect of sex, with the exception being LVF and XHA. About half of the measurements are significant for age, but there is no significance for a relationship between sex and age for L3 as a whole. TLV and XSL are the only two measurements selected by the stepwise procedure and by themselves correctly classify 82.7% and 82.8% of individuals, respectively, although there is a large discrepancy for XSL between the accuracy rates for males and females. When combined in a discriminant function, TLV and XSL correctly sex 86.1% of individuals (see B22, C22, D22).

LVF and XHF are the only two measurements that are not significant for sex in the fourth lumbar vertebra, and LSF, LIF, XSL, SLV, and TLV are all significant for age. The fourth lumbar does not display significant differences for an effect between sex and age when all measurements are considered together. TLV is the single most discriminating dimension for L4 with an R-square value of 0.5574. The best discriminant function equation is that which includes TLV, SLV, XHP, XHA, and SFB. This equation classifies males correctly 87.9% of the time and females 92.6% with an overall classification rate of 90.3%. The total accuracy level for the equation containing all six variables is only 88.2% (see B23, C23, D23).

With the exception of LVF, all dimensions measured for the fifth lumbar vertebra displayed significant differences for sex, though the p-value for WSF is only 0.0477. Similar to L4, several measurements are significant for age but L5 does not have a significant p-value to reject the hypothesis that there is no effect between sex and age. The stepwise analysis selected SLV and TLV as having the best sex discriminating ability of the measurements. Although SLV explains a higher percentage of the variation than TLV, 50% versus 11.5%, the discriminant function for TLV by itself proves to be slightly better than the function for SLV, with total classification rates of 86.9% versus

84.2%. However, the discriminant equation utilizing both variables correctly classifies 87.7% of individuals (see B24, C24, D24).

For the cervical vertebrae C3-C7, all measurements were shown to be statistically significant for sex and the majority of measurements also exhibited significance for age. Although the interaction effect of sex and age was found to be significant for the overall grouping of C3-C7, the effect between sex and age was not considered for each individual measurement since the changing size of the vertebrae may have a confounding effect; therefore, no variables were excluded from further analysis. XHP is the most important variable for discriminating sex with an R-square value of 0.3606. By itself, XHP only classifies 72.6% of males and 83.1% of females correctly. With the inclusion of additional variables, males are classified correctly between 82.5% and 91.9% while females are classified correctly between 86.1% and 90.3% (see B25, C25, D25).

As in the cervical grouping, the thoracic vertebral grouping demonstrates strongly significant values for sex for all variables and half the measurements are significant for age. Also like the cervical grouping, the thoracic grouping demonstrated an overall interaction effect between sex and age, but due to the confounding effects of the shifting characteristics of the thoracic vertebrae the relationship between sex and age for each measurement was not taken into account. XSL and IFB together account for 48% of the variation in the model and the discriminant function equation for these two variables results in a classification rate of 80.3% for males and 81.2% for females. The addition of one or more variables to the equation does not drastically increase the classification rate, with the high for males being 81.4% and for females being 84.3% using the equation with ten variables (see B26, C26, D26).

Every variable except for LVF proved to be significant for sex for the lumbar vertebral grouping. LSF, LIF, XHF, XSL, SLV, TLV, and XHP all displayed significance for age. The lumbar grouping did not show significance for the overall association between sex and age. The stepwise analysis selected nine variables to be included in discriminant function analysis with SLV and TLV being the two measurements with the most discriminating ability and having a combined R-square value of 0.5048. The discriminant analyses resulted in classification accuracy levels ranging from 81.1% to 87.4% for males and from 78.8% to 87.9% for females. The highest accuracy rates were achieved with the discriminant function for eight variables, though using one variable alone, SLV, still reaches an accuracy rate of 80% (see B27, C27, D27).

The grouping of C3-L5 also displayed strongly significant values for the effect of sex for all measurements. Like the other vertebral groupings, half the variables were also significant for age. As with both the cervical and thoracic groupings, the C3-L5 group as a whole exhibited significant differences for the effect of age on sex, but individual measurement results testing the relationship between sex and age were not included. Eleven variables were selected by the stepwise procedure with XSL and SFB being the most discriminating for sex. Together these two variables only account for 25% of the sexual variation. The classification rates for males from the discriminant analyses ranged from a low of 65.5% using one variable to a high of 77.1% using eleven variables and for females ranged from 63.3% for one variable to 80% using eleven variables, and a total accuracy rate of 75% is achieved using just four or five variables (see B28, C28, D28).

Summary Results

For most vertebra and vertebral groupings, the majority of measurements had p-values smaller than the alpha level of 0.05 and therefore the null hypothesis that sex has no effect is rejected. The most number of variables that did not show significant sex differences for a single vertebra or vertebral grouping was three. Certain measurements had higher frequencies of not being significant for sex than others. LVF was the most common measurement not significant for sex, having p-values greater than the alpha of 0.05 for 16 different vertebrae. LSF was not significant for sex for 5 different vertebrae; LIF was not significant for 3 different vertebrae; IFB was not significant for 2 different vertebrae; and WIF, SFB, XHF, and XHA were each not significant for one vertebra. For the vertebral groupings, only the lumbar group showed any variables that were not significant for sex and that was LVF only. A large majority of the dimensions showed very strong significance for sex with p-values of < .0001. In order to better understand which dimensions are more dimorphic, the Wilk's lambda values for the variable sex are provided. The lowest values indicate stronger dimorphism, with XSL having the lowest values for most vertebrae and the lengths and widths of the facets and LVF having the highest values, meaning they are least dimorphic (Refer to Appendix B).

All vertebrae and vertebral groupings displayed significance for age for multiple measurements, except for T9, which had no variables significant for age, and C1, which only showed SFB as significant for age. XSL, SLV, and TLV were the most common variables to be significant for age throughout the vertebral column. With only a couple of exceptions, XSL and SLV were both significant for age from C4-L5 as well as for the vertebral groupings (Refer to Appendix B).

The majority of vertebrae were not significant for the interaction effect between sex and age. Only C4 and T5 displayed any significance overall for the association between sex and age, and only T5 demonstrated significance for individual measurements. The C3-C7, thoracic, and C3-L5 groupings did show significant results for the interaction between sex and age as a whole, but given the possible confounding effect of the change in size throughout the vertebral column, results of individual measurements for each group were not taken into account (Refer to Appendix B).

Certain variables also proved to have better discriminating ability than others. Measurements that had higher R-square values included XSL, IFB, SFB, TLV, and SLV. XSL had the highest incidence, 13, of being selected first in the stepwise procedure for each vertebra and also had the highest overall R-square values and lower Wilk's lambda values compared to other variables that were selected first by stepwise. IFB and SFB were stronger discriminating variables for the cervical and thoracic vertebrae. TLV and SLV were very strong discriminating factors for the lumbar spine. TLV accounted for almost 50% of the sexual variation for each vertebra L1-L4, while SLV accounted for 50% of the variation for L5 (Refer to Appendix C).

The level of classification accuracy varied from one vertebra to the next. The lowest rate of classification for males was 65.5% for the C3-L5 vertebral grouping using one variable and the highest rate of classification for males was 97.6% for C3 using the discriminant function for five variables. The lowest accuracy level for females was 63.3% for the C3-L5 vertebral grouping using one variable and the highest percentage was 98% for T11 using three variables. The lowest overall percentage of individuals classified correctly was 64.4% for the C3-L5 grouping using one variable and the highest overall percentage was 94.6% for C7 with the discriminant function for five measurements (Refer to Appendix D).

Discussion and Conclusion

A number of researchers have studied the vertebrae (Anderson 1883; Cunningham 1886; Cyriax 1920, Struthers 1875; Smith 1902; Whitney 1926), but only a few have examined the extent of sexual dimorphism in the spine, and those have only investigated one or a few number of vertebrae. Previous research has noted sexual dimorphism in several vertebrae, including C1-C7 and T11 to L1, and accuracy for determining sex has ranged between 60 to 91% (MacLaughlin and Oldale 1992; Haugen 1994; Marino 1995; Wescott 2000; Pastor 2005). The current study sought to expand upon previous research by conducting metric and statistical analyses on the entire vertebral column to investigate the extent of sexual variation in the spine using a sample of 119 individuals from the William M. Bass Skeletal Collection. Multivariate analyses of variance were conducted to test for significance of effects of sex, age, and the interaction between sex and age and then discriminant analyses were performed to develop equations that could be used for estimating sex from the vertebrae.

The results of this study indicate that all vertebrae and vertebral groupings are sexually dimorphic and to some extent vary according to age. Although most of the measurements varied according to age for one or more vertebrae, only T5 demonstrated significant differences for any measurements for the interaction between sex and age. Length of the vertebral foramen (LVF) was the least sexually dimorphic trait, only being significant for sex in eight vertebrae: C1-3, C7-T3 and T5. A possible explanation for this lack of sexual dimorphism in LVF could relate to the width of the spinal cord as it moves down the column. There is an enlargement of the spinal cord at about the level of C3 and continues to approximately T2 (Gray 1973). The widest circumference is reached at the level of C6 and then decreases. Since the spinal cord is not as wide above C3 and below C6, there may be more "room" for variation in the vertebral foramen that could be attributed to sex. Although a second enlargement exists from about the level of T9 to T12 (Gray 1973), there is not a corresponding significance for sex in LVF above or below it as in the upper vertebral column. Lengths of the superior and inferior facets (LSF and LIF) were the next least sexually dimorphic measurements, not being significant for five and three vertebrae respectively. Inferior facet breadth (IFB) was not significant for two vertebrae and each of the following dimensions were not significant for one vertebra: width of the inferior facet (WIF), superior facet breadth (SFB), inferior facet breadth (IFB), maximum height of the facets (XHF), and maximum height of the anterior vertebral body (XHA). All other measurements were significantly sexually dimorphic for all vertebrae and vertebral groupings.

Only one dimension did not display any significant variation attributed to age for any of the vertebrae: LVF. Since the spinal cord passes through the vertebral foramen, effects of aging on the opening are probably minimal. Major effects of aging noted in the vertebral column include osteophyte formation and distortion of vertebral dimensions (Stewart 1958; Ericksen 1976, 1978a, 1978b), neither of which are likely to significantly change the length of the vertebral foramen opening. The most common variables to demonstrate significant effects from age are the maximum sagittal length (XSL) of the vertebra, sagittal length of the vertebral body (SLV), and transverse length of the vertebral body (TLV). The correlation between age and these variables is not surprising given Ericksen's (1976, 1978a, 1978b) findings. Although all measurements except LVF were significant for age for one or more vertebrae, the affect of age on sex was to a limited degree and was significant only for a couple dimensions. As stated previously, only C4 and T5 demonstrated any significance for sex*age, and only two individual measurements for T5 exhibited significance: IFB and XHP. Since only this one vertebra showed an interaction between sex and age it is difficult to draw conclusions as to why these two dimensions were significant for sex*age. As an individual ages, stress is placed on the joints of the vertebrae, resulting in broadening and lipping of the surfaces (Stewart 1958). This process could explain the reason for the age/sex interaction in the facet dimension, IFB. The interaction between sex and age in the height of the body, XHP, may be due to compression of the vertebral body over time from its weight-bearing function, as Ericksen (1976, 1978a, 1978b) noted in the lumbar column.

As mentioned in the results, certain measurements proved to be better at discriminating sex in the vertebrae than others. XSL was the single most discriminating variable, being selected first by stepwise analyses for 13 vertebrae and also for the thoracic and C3-L5 groupings. The three major parts of the vertebra that influence XSL are the body, vertebral foramen, and spinous process. As noted previously, LVF is not significant for sex for most vertebrae, so the vertebral foramen probably does not add much sexual dimorphism to XSL. The spinous process is an attachment site for muscles of the back (Gray 1973, White and Panjabi 1978). Since males tend to be more muscular than females (Krogman and Iscan 1986; Bass 1995), the spinous processes of males should tend to be larger than in females, thereby adding to the sexual dimorphism of the sagittal length measurement. The vertebral body acts as the major load-bearing agent for the vertebra, and since males tend to be bigger and more muscular than females, it would be expected that the vertebral body would be larger also in males, also adding to the sexual dimorphism of the XSL dimension. As discussed earlier, sex differences in growth rate patterns of the vertebral body in children have been observed (Roche 1972; Taylor and Twomey 1984; Gilsanz et al. 1994b). The increased growth early on in transverse vertebral body diameter in boys, and the subsequent overall increase in vertebral body size, explains why both TLV and SLV are also good sex discriminators, especially for the lower spine which supports most of the upper body weight.

Overall, the cervical vertebrae proved to be the best for estimating sex from individual vertebrae, with C1-C3 and C7 reaching accuracy levels at or above 90%. All of the individual thoracic vertebrae reached an accuracy of estimating sex of at least 84%, with half reaching 88% or higher. All lumbar vertebrae were also able to achieve accuracy rates of at least 84%, and L4 even reached 90%. The highest accuracy for the cervical grouping was 90.9%, for the thoracic grouping 82.9%, for the lumbar grouping 87.6%, and 78.5% for the whole vertebral column (C3-L5). This is supported by the Wilk's lambda values for each vertebra as a whole (see B29). The value for the C3-C7 grouping is lower than the lumbar grouping, followed by the thoracic grouping, and the value for the C3-L5 grouping is higher than the three other groupings. This means the order of most sexually dimorphic to least dimorphic is the C3-C7 grouping, lumbar grouping, thoracic grouping, and the C3-L5 grouping.

In order to determine sex from a vertebra, the vertebra number or grouping needs to be known in order to use the appropriate discriminant analysis table. After that, the measurement or measurements (in mm) needed for a given equation are multiplied by the corresponding coefficient, the sums are added and then the constant is added to the total. If the value is above 0, then the individual is classified as a male; if the value is below 0, then the individual is classified as a female. For example, if the first cervical vertebra of an unknown individual is to be used, then the discriminant function analysis table (D1) for C1 gives three possible equations, using inferior facet breadth (IFB), maximum sagittal length (XSL), and maximum width of the superior facet (WSF). Since the equation using just IFB and XSL has the highest percent sexing accuracy, then those two measurements (mm) would be collected from the vertebra. The measurements would then be multiplied by the corresponding coefficient listed under equation 2 and then summed. The constant for equation 2 would then be added and if the total were below 0 then the unknown individual would be classified as a female with 94.4% accuracy or if the total was above 0 then the individual would be classified as a male with 90.4% accuracy.

Although estimation of sex from the vertebrae would not be used in situations involving complete skeletal remains, it could be useful in instances where remains are incomplete or fragmentary. This study shows that estimating sex from a single vertebra can be done with similar levels of accuracy as other commonly used single bones used for sexing (Steele 1976; Black 1978; Iscan and Miller-Shaivitz 1984; Krogman and Iscan 1986; France 1988). For example, the femur can be correctly sexed about 85-90% of the time (Black 1978). Except for C4 and T6, all of the vertebrae in this study were accurately sexed between 79-90% of the time using just one variable. C4 and T6 had accuracy rates of 74.9% and 75.8, respectively, with use of just one variable. With the addition of more variables, accuracy levels up to 94.6% were achieved for a single vertebra.

Although it can be difficult to correctly identify the exact number, i.e. T4 versus T5, of a single vertebra when multiple vertebrae are missing, it is often possible to at least discern whether it is cervical, thoracic, or lumbar. For this reason, statistical analyses were conducted for each grouping of vertebrae. Since C1 and C2 are diagnostic and easily recognizable and since they display unique morphology, they were not included in the cervical grouping. Accuracy rates for C3-C7 vertebrae ranged from 77.8% using a single variable to 90.9% using six variables. For the thoracic vertebrae, accuracy between 73.3% and 82.9% was achieved. The lumbar vertebrae ranged from 80% accuracy to a high of 87.6%. This means that sex can still be estimated from an isolated vertebra with reasonable accuracy as long as the vertebral group can be distinguished. Discriminant equations were also calculated for C3-L5 combined, for use with an isolated unknown vertebra for which grouping cannot be identified. However, estimating sex for a vertebra using these equations is less accurate, with rates between 64.4% and 78.5%. Though most isolated vertebrae will at least have characteristics defining them as cervical, thoracic, or lumbar, being able to assess sex to some degree for a random vertebra, C3-L5, could be useful in certain situations.

Though this study demonstrated sexual dimorphism does exist throughout the vertebral column, only individuals of European ancestry were examined. Previous research has noted that ancestry is an important factor to take into consideration when looking at sexual variance in the vertebrae (Cunningham 1886; Shore 1931; Lanier 1939; Haugen 1994; Marino 1997; Duray et al. 1999; Wescott 2000). It has been noted that different ancestry groups have different accuracy results for estimating sex from the vertebrae. For example, Wescott (2000) observed that whites were correctly sexed 89%

of the time but only 81% for blacks. Future research needs to include a larger sample size including individuals of different ancestry to assess whether or not differences exist in sexual dimorphism between ancestry groups throughout the vertebral column.

In conclusion, sex can be estimated from a single vertebra, of either known number or unknown, with reasonable levels of accuracy in forensic or archaeological situations when skeletal remains are incomplete. Further research needs to be conducted to examine the effect of ancestry and its possible interaction with sex for the entire vertebral column. It would also be useful for samples from different populations to be studied to determine if any secular trends in sexual dimorphism exist in the vertebrae and to establish whether or not this research can be applied to non-modern populations.

Previous clinical research has utilized radiographs and computed tomography (CT) imaging (Payne and Spillane 1957; Katz et al. 1973; Hashimoto and Tak 1977; Eisenstein 1983; Hukuda and Kojima 2002; Kwon et al. 2004) for analyzing and studying vertebral dimensions. Both techniques, especially CT imaging since a 3-D image could be produced, would allow for dimensions to be measured across the vertebra that normally could not be recorded using standard measuring tools. With the advancement of technology, computer programs are being developed that can analyze images of bones taken with CT scans. Another technique is digitization, whereby points on a bone are recorded into a computer through the use of a special stylus and a computer image of the bone is formed from those data points. Recording a large number of measurements by hand is very time-consuming and being able to use a computer to analyze and take measurements could greatly reduce the amount of time necessary to collect data, allow more measurements to be taken, and could possibly lead to an as yet undefined measurement being revealed that could discriminate sex with an even higher accuracy. Future research using either CT scanning or digitization would be useful in further examining sexual dimorphism in the vertebral column.

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Appendices

Appendix A

Measurement Means and Standard Deviations

Contents of Appendix A

A 1. Measurement Means and Standard Deviations for C1

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
WFV	52	10.10	1.21	57	9.37	1.14
LSF	52	22.12	2.13	56	19.73	2.03
WSF	51	12.63	1.97	56	11.50	1.69
LIF	51	17.90	1.55	56	16.71	1.49
WIF	52	17.79	1.66	56	15.75	1.48
SFB	51	50.98	3.04	56	49.18	2.80
IFB	52	49.40	2.23	56	45.20	2.35
XHF	52	23.33	2.18	56	21.36	2.13
LVF	52	32.06	1.98	55	29.93	1.90
XSL	52	48.31	2.65	55	43.64	2.43

A 2. Measurements Means and Standard Deviations for C2

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
XDH	52	42.83	2.74	56	39.30	2.16
XDW	54	12.20	0.81	56	11.61	0.82
LSF	54	18.91	1.29	56	17.07	1.37
WSF	54	18.43	1.63	56	16.05	1.44
LIF	52	12.58	2.23	55	11.91	1.75
WIF	52	13.27	1.74	55	12.07	1.29
SFB	54	49.11	2.33	56	44.84	2.10
IFB	52	51.38	3.06	55	48.07	2.70
XHF	52	26.38	2.21	55	23.67	2.49
LVF	54	17.67	2.36	55	16.09	1.72
XSL	53	53.15	2.12	56	47.54	2.54

A 3. Measurements Means and Standard Deviations for C3

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	48	12.19	2.26	56	11.59	1.71
WSF	48	12.94	1.37	56	11.79	1.26
LIF	50	12.92	2.33	57	11.91	1.93
WIF	50	13.58	2.14	57	12.49	1.47
SFB	48	51.35	3.06	56	48.27	2.33
IFB	50	54.78	3.65	57	50.63	2.76
XHF	48	24.00	2.29	57	21.33	2.12
LVF	48	14.73	1.25	57	13.93	1.62
XSL	42	47.60	2.42	55	43.33	2.22
SLV	48	18.38	1.82	57	15.88	1.51
TLV	48	22.40	1.84	58	19.84	1.88
XHP	48	15.35	1.10	57	13.51	1.00
XHA	48	14.92	1.27	58	13.05	1.07

A 4. Measurements Means and Standard Deviations for C4

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	47	13.04	2.07	54	12.13	1.84
WSF	47	13.34	1.65	54	12.33	1.39
LIF	48	12.42	1.83	54	11.31	1.81
WIF	48	13.94	1.72	54	13.02	1.73
SFB	46	53.78	3.16	54	50.22	2.69
IFB	48	55.79	2.92	54	51.87	2.86
XHF	48	23.98	2.05	54	21.83	1.97
LVF	49	14.04	1.35	54	13.50	1.60
XSL	41	47.85	3.17	50	43.68	2.24
SLV	49	18.53	1.96	54	16.54	1.75
TLV	49	22.55	2.27	54	20.30	2.28
XHP	49	15.02	1.15	54	13.19	0.87
XHA	49	14.24	1.35	54	12.41	1.21

A 5. Measurements Means and Standard Deviations for C5

	MALES			FEMALES		

Var	N	Mean	SD	N	Mean	SD
LSF	51	12.02	1.92	54	11.15	1.42
WSF	51	13.94	1.82	54	12.46	1.87
LIF	51	11.39	1.66	50	10.62	1.90
WIF	51	14.31	1.92	51	13.37	1.84
SFB	51	55.45	2.93	54	51.07	3.16
IFB	50	57.36	3.44	51	52.86	2.99
XHF	51	23.39	2.00	50	21.44	2.05
LVF	52	14.29	1.29	54	13.74	1.44
XSL	43	50.74	3.66	43	45.30	2.90
SLV	52	19.48	2.08	50	16.96	1.76
TLV	52	23.42	2.94	51	20.96	2.15
XHP	52	14.79	1.18	51	13.08	0.82
XHA	52	13.83	1.26	51	12.12	0.82

A 6. Measurements Means and Standard Deviations for C6

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	52	11.25	1.47	52	10.42	1.71
WSF	52	13.94	1.94	52	13.06	1.76
LIF	51	10.84	1.24	53	10.34	1.79
WIF	51	15.43	2.22	53	14.19	1.52
SFB	52	56.48	3.27	50	51.92	3.00
IFB	51	56.55	2.66	52	52.06	2.66
XHF	51	24.43	1.78	49	22.18	1.87
LVF	51	14.12	1.58	52	13.65	1.52
XSL	45	56.62	4.46	49	50.65	4.46
SLV	49	20.39	2.23	52	17.52	2.05
TLV	51	25.39	2.85	52	23.27	2.15
XHP	51	14.63	1.20	52	13.21	0.72
XHA	51	13.76	1.23	52	12.40	0.91

A 7. Measurements Means and Standard Deviations for C7

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	56	10.71	1.49	58	10.09	1.23
WSF	56	15.32	2.05	58	14.43	1.50
LIF	57	13.09	1.83	58	12.17	2.12
WIF	57	16.35	2.61	58	15.07	2.22
SFB	56	56.41	2.86	57	51.46	2.49
IFB	57	52.63	3.43	57	46.95	3.78
XHF	56	28.34	2.65	58	25.38	2.10
LVF	55	14.24	1.35	57	13.74	1.23
XSL	56	63.54	3.89	57	56.32	3.01
SLV	55	19.36	2.08	58	16.72	2.06
TLV	56	29.82	2.61	58	27.26	2.02
XHP	55	16.13	1.04	58	14.52	0.84
XHA	56	15.41	1.36	58	13.90	1.00

A 8. Measurements Means and Standard Deviations for T1

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	60	13.25	2.01	59	11.95	1.60
WSF	60	16.47	2.48	59	14.46	2.24
LIF	60	12.93	1.98	58	11.90	1.64
WIF	60	14.48	1.68	58	12.97	1.46
SFB	60	52.55	3.71	59	46.31	4.44
IFB	60	45.25	2.55	58	40.09	2.92
XHF	60	31.37	2.48	58	29.03	2.64
LVF	60	14.97	1.12	59	14.39	1.02
XSL	60	66.42	3.32	58	58.84	3.27
SLV	60	19.22	1.53	59	16.80	1.56
TLV	60	35.47	2.32	59	31.66	2.44
XHP	59	18.54	1.10	59	16.66	0.99
XHA	60	17.07	1.22	59	15.56	1.04

A 9. Measurements Means and Standard Deviations for T2

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	59	12.85	1.75	59	11.88	1.63
WSF	59	13.59	1.68	59	12.34	1.66
LIF	58	12.36	1.71	58	11.52	1.39
WIF	58	12.79	1.40	58	11.74	1.29
SFB	59	44.25	2.47	59	39.19	3.09
IFB	58	39.72	2.58	58	35.45	2.52
XHF	58	34.05	2.58	58	30.40	2.26
LVF	59	15.29	1.19	59	14.46	1.02
XSL	59	66.88	3.64	57	59.82	3.60
SLV	59	20.97	1.68	58	18.55	1.73
TLV	58	34.62	3.09	58	30.34	2.27
XHP	58	19.61	1.34	58	17.52	1.05
XHA	57	18.60	1.60	56	16.95	1.07

A 10. Measurements Means and Standard Deviations for T3

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	59	12.15	1.60	57	11.35	1.37
WSF	59	12.07	1.70	58	11.16	1.40
LIF	59	12.22	1.19	56	11.25	1.12
WIF	60	12.30	1.46	56	11.14	1.49
SFB	59	38.15	2.61	58	34.16	2.22
IFB	60	37.37	2.65	56	33.61	2.49
XHF	59	34.71	2.37	56	31.63	1.87
LVF	60	15.35	1.45	58	14.81	1.03
XSL	59	68.39	4.11	54	60.59	3.96
SLV	59	23.69	2.30	55	21.00	2.19
TLV	59	31.92	3.04	54	27.83	2.41
XHP	59	19.98	1.31	56	18.36	0.90
XHA	59	19.25	1.36	55	17.44	1.29

A 11. Measurements Means and Standard Deviations for T4

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	59	11.90	1.53	57	10.89	1.13
WSF	59	11.90	1.43	57	10.75	1.61
LIF	58	12.16	1.24	55	11.09	1.19
WIF	58	11.78	1.41	55	10.60	1.42
SFB	59	36.14	2.29	57	32.33	2.56
IFB	58	36.05	2.67	55	33.02	2.72
XHF	58	34.93	2.27	54	32.09	1.83
LVF	59	15.34	1.49	55	15.27	1.16
XSL	59	68.54	4.76	54	60.54	4.48
SLV	59	25.66	2.04	54	22.54	2.00
TLV	59	30.86	2.76	55	27.00	2.13
XHP	58	20.47	1.37	54	19.02	0.98
XHA	59	19.36	1.56	53	18.06	0.86

A 12. Measurements Means and Standard Deviations for T5

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	59	11.49	1.06	56	11.02	1.26
WSF	59	11.81	1.84	56	10.89	1.55
LIF	60	12.02	1.40	58	11.09	1.19
WIF	60	11.55	1.57	58	10.62	1.76
SFB	59	34.83	2.65	56	31.54	2.26
IFB	60	35.87	2.95	58	32.19	2.68
XHF	59	35.34	2.40	56	32.57	1.88
LVF	59	15.86	1.54	56	15.36	1.17
XSL	59	67.90	4.36	53	60.53	4.51
SLV	60	27.28	1.92	54	24.50	2.34
TLV	60	31.43	2.61	56	27.98	2.19
XHP	59	21.32	1.18	56	19.86	0.98
XHA	60	19.58	1.80	55	18.33	1.17

A 13. Measurements Means and Standard Deviations for T6

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	59	11.59	1.65	57	10.75	1.29
WSF	59	11.76	1.81	57	10.72	1.67
LIF	59	11.93	1.39	52	11.10	1.24
WIF	59	11.59	1.42	52	10.31	1.23
SFB	59	34.53	3.19	57	31.21	2.59
IFB	59	35.69	2.46	52	31.65	2.59
XHF	59	36.03	2.31	52	33.40	1.93
LVF	59	15.58	1.57	56	15.23	1.26
XSL	58	68.10	4.45	50	61.62	4.24
SLV	59	29.41	2.37	52	25.85	2.40
TLV	59	32.42	2.57	52	28.52	2.38
XHP	59	21.98	1.38	52	20.31	1.06
XHA	59	19.92	1.25	51	18.24	1.41

A 14. Measurements Means and Standard Deviations for T7

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	60	11.73	1.49	52	10.85	1.50
WSF	60	11.42	1.54	52	10.21	1.61
LIF	58	11.53	1.39	52	11.00	1.58
WIF	58	11.69	1.59	52	10.42	1.19
SFB	60	34.22	2.89	52	30.62	2.47
IFB	57	36.25	2.91	52	32.48	2.41
XHF	58	37.02	2.57	50	34.62	2.03
LVF	59	15.41	1.76	52	15.21	1.24
XSL	56	70.55	4.79	47	63.81	4.23
SLV	55	30.71	2.41	49	27.02	2.21
TLV	56	33.96	2.85	50	29.72	2.34
XHP	55	22.29	1.41	50	20.80	1.07
XHA	56	19.63	1.65	50	18.36	1.40

A 15. Measurements Means and Standard Deviations for T8

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	57	11.21	1.36	53	10.87	1.44
WSF	57	11.61	1.64	53	10.25	1.27
LIF	57	11.65	1.68	52	10.65	1.19
WIF	57	12.12	1.56	52	10.83	1.45
SFB	57	34.75	2.78	53	31.02	2.43
IFB	57	37.21	2.97	52	33.21	2.69
XHF	57	37.70	2.49	51	34.65	2.16
LVF	58	15.43	1.40	53	15.19	1.18
XSL	57	73.44	4.27	52	65.81	4.41
SLV	57	32.61	2.99	52	28.15	2.61
TLV	57	35.89	3.32	53	31.43	2.45
XHP	57	22.67	1.20	53	20.98	1.17
XHA	57	20.14	1.61	52	18.69	1.71

A 16. Measurements Means and Standard Deviations for T9

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	56	11.48	1.83	52	11.00	1.37
WSF	56	11.77	1.50	52	10.29	1.24
LIF	55	11.93	1.80	51	10.96	1.52
WIF	55	13.11	1.80	51	11.63	1.47
SFB	56	36.41	2.98	52	31.90	2.19
IFB	55	39.51	3.60	51	34.88	2.80
XHF	54	38.04	2.57	50	35.12	2.24
LVF	57	15.16	1.52	52	15.00	1.30
XSL	53	74.98	4.50	50	66.96	3.94
SLV	53	32.98	2.93	51	28.71	2.59
TLV	54	37.94	3.21	50	33.42	2.90
XHP	54	23.22	1.48	50	21.60	1.20
XHA	54	21.57	1.60	50	20.12	1.35

A 17. Measurements Means and Standard Deviations for T10

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	56	11.61	1.66	52	11.02	1.29
WSF	56	12.21	1.81	52	11.00	1.37
LIF	55	12.69	1.71	54	11.78	1.61
WIF	55	13.84	1.88	54	12.20	1.53
SFB	56	38.43	3.55	52	33.71	2.67
IFB	55	40.80	3.88	53	35.21	2.67
XHF	54	40.48	2.67	52	37.75	2.35
LVF	56	15.41	1.35	52	15.13	1.21
XSL	55	75.62	4.08	50	67.82	3.90
SLV	56	33.48	2.78	52	29.23	2.52
TLV	54	40.91	3.45	52	35.92	2.96
XHP	54	24.59	1.56	52	22.94	1.32
XHA	57	22.79	1.94	53	21.38	1.36

A 18. Measurements Means and Standard Deviations for T11

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	55	12.18	1.99	54	11.19	1.65
WSF	55	12.71	2.13	54	11.30	1.83
LIF	58	13.34	2.00	57	12.39	2.27
WIF	58	11.97	1.94	57	10.05	1.73
SFB	55	39.49	4.02	54	34.31	2.97
IFB	58	37.16	4.44	57	31.91	3.49
XHF	54	44.67	3.36	53	41.25	3.27
LVF	55	16.05	1.61	54	15.78	1.34
XSL	55	76.00	4.28	50	68.16	3.81
SLV	56	33.66	2.66	52	29.58	2.67
TLV	55	44.29	3.71	52	38.88	2.82
XHP	54	26.50	1.69	53	24.79	1.43
XHA	55	23.73	2.03	52	22.33	1.49

A 19. Measurements Means and Standard Deviations for T12

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	58	13.34	2.28	55	12.00	2.10
WSF	58	11.98	1.86	55	10.33	1.82
LIF	59	14.39	2.05	56	13.45	1.99
WIF	59	10.75	1.45	56	10.07	1.45
SFB	58	37.38	4.03	55	32.31	3.19
IFB	59	29.49	3.18	56	28.36	3.65
XHF	58	47.52	3.03	55	44.76	2.86
LVF	58	17.17	1.51	55	17.00	1.26
XSL	58	78.78	4.18	54	71.78	3.98
SLV	59	34.07	2.61	54	30.19	2.73
TLV	58	47.28	3.48	54	40.98	3.17
XHP	58	28.16	1.52	54	26.52	1.49
XHA	58	25.21	1.81	52	24.27	1.33

A 20. Measurements Means and Standard Deviations for L1

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	59	14.15	2.47	57	13.35	2.23
WSF	59	13.17	1.73	57	11.89	1.88
LIF	58	16.05	2.42	56	15.04	1.93
WIF	58	12.53	1.59	57	11.35	1.40
SFB	59	30.92	3.22	57	29.63	3.34
IFB	58	29.38	3.20	57	27.88	2.80
XHF	57	49.79	3.17	56	47.00	2.70
LVF	58	17.47	1.49	57	17.56	1.31
XSL	56	84.07	4.10	56	76.79	4.52
SLV	55	35.13	2.40	56	31.21	2.92
TLV	55	49.38	3.29	56	43.25	3.09
XHP	57	29.46	1.58	57	27.89	1.51
XHA	56	27.00	1.54	55	25.89	1.77

A 21. Measurements Means and Standard Deviations for L2

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	57	16.42	2.31	57	15.04	1.96
WSF	57	15.33	1.77	57	14.19	1.75
LIF	57	16.82	2.55	56	15.45	2.42
WIF	57	14.56	1.68	56	12.86	1.42
SFB	57	31.46	3.06	57	29.54	2.67
IFB	57	33.28	4.69	56	30.09	3.89
XHF	56	51.86	3.29	56	48.73	3.02
LVF	57	16.42	1.52	57	16.89	1.38
XSL	56	88.39	4.43	55	81.02	3.94
SLV	56	36.43	2.74	56	32.59	2.83
TLV	56	51.45	3.42	56	45.43	3.22
XHP	56	29.61	1.64	56	28.23	1.51
XHA	59	28.46	1.84	56	27.68	1.75

A 22. Measurements Means and Standard Deviations for L3

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	56	16.86	2.73	55	15.69	2.38
WSF	56	17.29	1.99	55	15.75	2.11
LIF	57	17.23	2.70	56	15.55	2.42
WIF	57	14.74	1.76	56	13.29	1.69
SFB	56	35.29	4.37	55	31.98	3.63
IFB	57	38.21	5.14	56	34.91	5.05
XHF	56	51.13	3.51	55	47.65	3.07
LVF	56	15.70	1.81	55	15.89	1.92
XSL	56	89.96	4.40	54	82.28	3.80
SLV	57	36.96	2.81	54	33.00	2.39
TLV	57	53.93	3.17	53	47.45	2.92
XHP	57	29.28	1.74	53	27.75	1.56
XHA	58	29.34	1.77	53	28.66	1.49

A 23. Measurements Means and Standard Deviations for L4

MALES				FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	59	17.42	3.03	56	16.20	3.01
WSF	59	18.02	2.29	56	16.16	2.29
LIF	59	17.31	2.47	54	16.06	2.64
WIF	59	15.98	2.29	54	14.28	2.21
SFB	59	40.00	5.17	56	36.52	4.96
IFB	59	47.44	6.93	54	42.87	6.98
XHF	59	46.90	7.14	54	44.91	3.39
LVF	59	16.46	2.46	56	16.07	1.83
XSL	57	88.14	5.29	55	80.35	4.22
SLV	58	37.38	2.48	56	33.00	2.23
TLV	59	55.85	3.15	55	48.98	3.02
XHP	59	28.37	1.93	54	26.43	1.46
XHA	59	29.49	1.61	55	28.62	1.57

A 24. Measurements Means and Standard Deviations for L5

MALES				FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	57	18.25	2.65	53	17.02	2.82
WSF	57	18.54	2.04	53	17.49	2.37
LIF	50	18.78	3.03	47	16.32	2.44
WIF	51	17.78	2.23	47	15.66	2.00
SFB	57	49.44	6.70	53	44.87	6.72
IFB	51	56.27	5.44	47	51.72	6.99
XHF	48	43.94	3.51	44	41.20	3.23
LVF	54	17.59	2.85	45	16.42	1.79
XSL	51	81.00	6.34	44	75.23	5.17
SLV	55	37.15	2.58	47	32.38	2.35
TLV	53	57.09	4.26	46	49.50	3.30
XHP	52	25.94	1.95	46	24.26	1.64
XHA	53	30.11	2.09	47	28.89	1.60

A 25. Measurements Means and Standard Deviations for Cervical, C3-C7

MALES				FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	254	11.80	2.01	274	11.07	1.75
WSF	254	13.94	1.96	274	12.83	1.81
LIF	257	12.15	2.00	272	11.31	2.03
WIF	257	14.77	2.38	273	13.64	2.00
SFB	253	54.79	3.59	271	50.56	3.01
IFB	256	55.35	3.64	271	50.80	3.69
XHF	254	24.92	2.85	268	22.49	2.54
LVF	255	14.28	1.38	274	13.72	1.48
XSL	227	53.96	7.30	254	48.06	5.98
SLV	253	19.24	2.15	271	16.70	1.90
TLV	256	24.86	3.80	273	22.37	3.49
XHP	255	15.20	1.25	272	13.52	1.01
XHA	256	14.45	1.44	273	12.81	1.20

A 26. Measurements Means and Standard Deviations for Thoracic

MALES				FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	697	12.07	1.83	663	11.24	1.54
WSF	697	12.45	2.25	664	11.18	2.00
LIF	697	12.43	1.82	659	11.53	1.70
WIF	697	12.32	1.89	659	11.06	1.70
SFB	697	38.46	5.98	664	34.17	5.23
IFB	696	37.51	4.76	658	33.53	3.93
XHF	688	37.57	5.10	645	34.69	4.97
LVF	699	15.58	1.56	661	15.23	1.34
XSL	688	71.20	5.84	629	63.75	5.67
SLV	692	28.53	5.56	642	24.99	4.98
TLV	689	36.32	5.88	645	31.93	5.00
XHP	684	22.39	3.06	647	20.70	3.03
XHA	691	20.54	2.75	638	19.08	2.70

A 27. Measurements Means and Standard Deviations for Lumbar

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	288	16.61	2.98	278	15.43	2.78
WSF	288	16.45	2.80	278	15.05	2.82
LIF	281	17.20	2.75	269	15.66	2.40
WIF	282	15.06	2.56	270	13.40	2.25
SFB	288	37.40	8.27	278	34.37	7.22
IFB	282	40.60	10.92	270	36.94	10.06
XHF	276	48.84	5.26	265	46.11	3.97
LVF	284	16.72	2.19	270	16.58	1.76
XSL	276	86.42	5.89	264	79.27	5.02
SLV	281	36.62	2.71	269	32.43	2.63
TLV	280	53.54	4.44	266	46.81	3.86
XHP	281	28.57	2.21	266	27.01	2.07
XHA	285	28.87	2.06	266	27.91	1.98

A 28. Measurements Means and Standard Deviations for C3-L5

	MALES			FEMALES		
Var	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
LSF	1239	13.07	2.93	1215	12.16	2.63
WSF	1239	13.69	2.84	1216	12.44	2.69
LIF	1235	13.46	2.92	1200	12.40	2.62
WIF	1236	13.46	2.52	1202	12.17	2.27
SFB	1238	41.55	9.16	1213	37.88	8.67
IFB	1234	41.92	9.56	1199	38.20	9.08
XHF	1218	37.48	9.21	1178	24.48	9.04
LVF	1238	15.57	1.87	1205	15.19	1.76
XSL	1191	71.44	12.17	1147	63.85	11.89
SLV	1226	28.46	7.27	1182	24.79	6.65
TLV	1225	37.86	10.95	1184	33.07	9.45
XHP	1220	22.31	5.13	1185	20.47	5.19
XHA	1232	21.20	5.39	1177	19.62	5.63

Appendix B

MANOVA Results

Contents of Appendix B

B 1. C1 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
WFV	0.0013	0.9249	0.9017
LSF	< .0001	0.9811	0.7655
WSF	0.0025	0.9839	0.9129
LIF	< .0001	0.5357	0.8525
WIF	< .0001	0.8344	0.7038
SFB	0.0004	0.0498	0.8911
IFB	< .0001	0.5077	0.5298
XHF	< .0001	0.0972	0.8149
LVF	< .0001	0.8376	0.7625
XSL	< .0001	0.1904	0.5423

B 2. C2 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
XDH	<.0001	0.1798	0.6590
XDW	0.0002	0.2859	0.8779
LSF	<.0001	0.7789	0.6765
WSF	<.0001	0.4424	0.6264
LIF	0.0840	0.6361	0.9724
WIF	<.0001	0.0858	0.8644
SFB	<.0001	0.0456	0.5130
IFB	<.0001	0.1229	0.7484
XHF	<.0001	0.3013	0.7483
LVF	0.0002	0.8500	0.8762
XSL	<.0001	0.0329	0.4003

B 3. C3 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	0.1536	0.2438	0.9806
WSF	<.0001	0.1614	0.8236
LIF	0.0310	0.0198	0.9595
WIF	0.0011	0.1870	0.8965
SFB	<.0001	0.2382	0.7355
IFB	<.0001	0.1530	0.6827
XHF	<.0001	0.2567	0.7042
LVF	0.0082	0.3276	0.9303
XSL	<.0001	0.0006	0.5453
SLV	<.0001	0.1691	0.6232
TLV	<.0001	0.3017	0.6997
XHP	<.0001	0.7659	0.5470
XHA	<.0001	0.6434	0.6276

B 4. C4 MANOVA -- significance of variables by sex, age, and sex*age

	TYPE III SS			
VARIABLE	SEX	AGE	SEX*AGE	WILK'S LAMBDA
LSF	0.0348	0.0048	0.5618	0.9544
WSF	0.0007	0.0036	0.3392	0.8857
LIF	0.0017	0.1306	0.2893	0.8945
WIF	0.0033	0.2417	0.4375	0.9056
SFB	<.0001	0.0042	0.4770	0.7281
IFB	<.0001	0.0040	0.9531	0.6621
XHF	<.0001	0.0492	0.3015	0.7768
LVF	0.0646	0.4550	0.1811	0.9613
XSL	<.0001	0.0033	0.1775	0.6200
SLV	<.0001	0.0013	0.2062	0.7725
TLV	<.0001	0.1837	0.1580	0.8172
XHP	<.0001	0.1777	0.4539	0.5213
XHA	<.0001	0.4869	0.7864	0.6960

B 5. C5 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	0.0166	0.3020	0.9351
WSF	<.0001	0.0163	0.8402
LIF	0.0326	0.4079	0.9475
WIF	0.1220	0.3661	0.9729
SFB	<.0001	0.2282	0.6284
IFB	<.0001	0.2442	0.5994
XHF	<.0001	0.1661	0.8001
LVF	0.2391	0.6066	0.9820
XSL	<.0001	0.0010	0.5727
SLV	<.0001	0.0004	0.7080
TLV	0.0001	0.2768	0.8391
XHP	<.0001	0.1393	0.5739
XHA	<.0001	0.7060	0.6020

B 6. C6 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	0.0936	0.8579	0.9682
WSF	0.0387	0.1071	0.9547
LIF	0.2141	0.0014	0.9861
WIF	0.0025	0.1703	0.9036
SFB	<.0001	0.8470	0.6063
IFB	<.0001	0.1992	0.5644
XHF	<.0001	0.9423	0.7197
LVF	0.0676	0.4564	0.9617
XSL	<.0001	0.7212	0.6808
SLV	<.0001	0.0002	0.6811
TLV	0.0004	0.4068	0.8679
XHP	<.0001	0.7902	0.6835
XHA	<.0001	0.1161	0.7206

B 7. C7 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	0.0112	0.3988	0.9417
WSF	0.0066	0.0213	0.9361
LIF	0.0299	0.1520	0.9575
WIF	0.0072	0.2917	0.9350
SFB	<.0001	0.4854	0.5295
IFB	<.0001	0.1998	0.6240
XHF	<.0001	0.2396	0.7140
LVF	0.0497	0.2305	0.9649
XSL	<.0001	0.0057	0.4823
SLV	<.0001	0.0057	0.7036
TLV	<.0001	0.3398	0.7699
XHP	<.0001	0.5061	0.5761
XHA	<.0001	0.1082	0.6947

B 8. T1 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	0.0003	0.2672	0.8944
WSF	<.0001	0.7549	0.8607
LIF	0.0015	0.3103	0.9164
WIF	<.0001	0.2258	0.8105
SFB	<.0001	0.2030	0.6455
IFB	<.0001	0.7980	0.5300
XHF	<.0001	0.1981	0.8224
LVF	0.0071	0.2903	0.9400
XSL	<.0001	0.0013	0.4332
SLV	<.0001	<.0001	0.6327
TLV	<.0001	0.5359	0.6084
XHP	<.0001	0.6757	0.5354
XHA	<.0001	0.7856	0.6927

B 9. T2 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	0.0017	0.7413	0.9130
WSF	0.0002	0.7251	0.8805
LIF	0.0067	0.2438	0.9377
WIF	<.0001	0.1933	0.8687
SFB	<.0001	0.9622	0.5523
IFB	<.0001	0.3993	0.5890
XHF	<.0001	0.8001	0.6214
LVF	0.0001	0.5800	0.8696
XSL	<.0001	<.0001	0.5211
SLV	<.0001	0.0010	0.6819
TLV	<.0001	0.7769	0.6218
XHP	<.0001	0.3507	0.5466
XHA	<.0001	0.5394	0.7243

B 10. T3 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	0.0085	0.2419	0.9423
WSF	0.0019	0.2861	0.9186
LIF	<.0001	0.0844	0.8668
WIF	<.0001	0.2835	0.8710
SFB	<.0001	0.4691	0.5872
IFB	<.0001	0.0057	0.6508
XHF	<.0001	0.0253	0.6742
LVF	0.0149	0.7368	0.9472
XSL	<.0001	0.0040	0.5229
SLV	<.0001	0.0002	0.7449
TLV	<.0001	0.0726	0.6477
XHP	<.0001	0.5192	0.6526
XHA	<.0001	0.4385	0.6863

B 11. T4 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	<.0001	0.4130	0.8538
WSF	0.0002	0.4832	0.8804
LIF	<.0001	0.0895	0.8486
WIF	<.0001	0.0209	0.8640
SFB	<.0001	0.2763	0.6358
IFB	<.0001	0.0139	0.7649
XHF	<.0001	0.0564	0.6782
LVF	0.6931	0.6638	0.9984
XSL	<.0001	0.0006	0.5703
SLV	<.0001	0.0006	0.6302
TLV	<.0001	0.9894	0.6293
XHP	<.0001	0.9352	0.7285
XHA	<.0001	0.8195	0.8026

B 12. T5 MANOVA -- significance of variables by sex, age, and sex*age

	TYPE III SS			
VARIABLE	SEX	AGE	AGE*SEX	WILK'S LAMBDA
LSF	0.0139	0.1679	0.1275	0.9483
WSF	0.0043	0.0005	0.2313	0.9415
LIF	0.0002	0.5513	0.3716	0.8821
WIF	0.0057	0.2494	0.2494	0.9338
SFB	<.0001	0.0208	0.1367	0.7011
IFB	0.4075	0.0269	0.0251	0.7169
XHF	<.0001	0.0264	0.7224	0.7102
LVF	0.0354	0.8895	0.5437	0.9585
XSL	<.0001	0.0084	0.1146	0.6016
SLV	<.0001	<.0001	0.0973	0.7273
TLV	<.0001	0.1437	0.4009	0.6762
XHP	0.0007	0.2109	0.0378	0.6898
XHA	0.0002	0.8771	0.2930	0.8739

B 13. T6 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	0.0122	0.2811	0.9423
WSF	0.0049	0.0390	0.9314
LIF	0.0011	0.1454	0.9042
WIF	<.0001	0.2819	0.8161
SFB	<.0001	0.2541	0.7490
IFB	<.0001	0.1239	0.6177
XHF	<.0001	0.0475	0.7290
LVF	0.1129	0.6762	0.9760
XSL	<.0001	0.0182	0.6519
SLV	<.0001	0.0129	0.6493
TLV	<.0001	0.0943	0.6198
XHP	<.0001	0.8915	0.7124
XHA	<.0001	0.9098	0.7058

B 14. T7 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	0.0003	0.2833	0.8819
WSF	0.0001	0.4252	0.8642
LIF	0.0723	0.3880	0.9702
WIF	<.0001	0.1124	0.8266
SFB	<.0001	0.4345	0.6962
IFB	<.0001	0.6010	0.6802
XHF	<.0001	0.0531	0.7919
LVF	0.4374	0.3517	0.9953
XSL	<.0001	0.0455	0.6445
SLV	<.0001	0.0083	0.6207
TLV	<.0001	0.0870	0.6111
XHP	<.0001	0.2992	0.7431
XHA	0.0001	0.1989	0.8493

B 15. T8 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	0.1952	0.8696	0.9838
WSF	<.0001	0.0298	0.8240
LIF	0.0012	0.5485	0.9044
WIF	<.0001	0.6771	0.8548
SFB	<.0001	0.6034	0.6691
IFB	<.0001	0.8325	0.6683
XHF	<.0001	0.2428	0.6952
LVF	0.3139	0.2537	0.9917
XSL	<.0001	0.1036	0.5659
SLV	<.0001	0.0132	0.6239
TLV	<.0001	0.1189	0.6352
XHP	<.0001	0.0515	0.6606
XHA	<.0001	0.3812	0.8360

B 16. T9 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	0.1631	0.5539	0.9808
WSF	<.0001	0.1154	0.7783
LIF	0.0086	0.8786	0.9286
WIF	<.0001	0.9194	0.8506
SFB	<.0001	0.9195	0.5797
IFB	<.0001	0.6573	0.6824
XHF	<.0001	0.1397	0.7489
LVF	0.3050	0.2964	0.9906
XSL	<.0001	0.1179	0.5182
SLV	<.0001	0.2923	0.6169
TLV	<.0001	0.0747	0.6722
XHP	<.0001	0.1010	0.7549
XHA	<.0001	0.4371	0.7919

B 17. T10 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	0.1250	0.3345	0.9743
WSF	0.0002	0.0342	0.8807
LIF	0.0071	0.2917	0.9323
WIF	<.0001	0.8010	0.8245
SFB	<.0001	0.6802	0.6366
IFB	<.0001	0.4033	0.5959
XHF	<.0001	0.1421	0.7639
LVF	0.1498	0.9164	0.9791
XSL	<.0001	0.0047	0.5244
SLV	<.0001	0.0237	0.6286
TLV	<.0001	0.0180	0.6117
XHP	<.0001	0.2610	0.7218
XHA	<.0001	0.8595	0.8113

B 18. T11 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	0.0202	0.9793	0.9459
WSF	0.0032	0.5020	0.9176
LIF	0.0225	0.2451	0.9524
WIF	<.0001	0.1649	0.7867
SFB	<.0001	0.5688	0.6580
IFB	<.0001	0.0283	0.7133
XHF	<.0001	0.0027	0.8025
LVF	0.3692	0.7113	0.9923
XSL	<.0001	0.0029	0.5289
SLV	<.0001	0.0103	0.6006
TLV	<.0001	0.0167	0.5962
XHP	<.0001	0.1503	0.7704
XHA	0.0003	0.5625	0.8756

B 19. T12 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	0.0030	0.4814	0.9211
WSF	<.0001	0.8843	0.8256
LIF	0.0088	0.3134	0.9394
WIF	0.0207	0.5166	0.9517
SFB	<.0001	0.0739	0.6702
IFB	0.1435	0.5703	0.9788
XHF	<.0001	0.2421	0.8117
LVF	0.5171	0.3505	0.9967
XSL	<.0001	0.0032	0.5741
SLV	<.0001	0.0051	0.6384
TLV	<.0001	0.0019	0.5304
XHP	<.0001	0.5776	0.7593
XHA	0.0029	0.5976	0.9202

B 20. L1 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	0.0325	0.2785	0.9602
WSF	0.0003	0.6060	0.8826
LIF	0.0498	0.4063	0.9658
WIF	0.0001	0.8831	0.8661
SFB	0.1116	0.6565	0.9747
IFB	0.0053	0.9668	0.9272
XHF	<.0001	0.1558	0.8242
LVF	0.8481	0.0853	0.9990
XSL	<.0001	0.0102	0.5658
SLV	<.0001	0.0153	0.5995
TLV	<.0001	0.0033	0.4765
XHP	<.0001	0.1724	0.7699
XHA	0.0014	0.3962	0.9097

B 21. L2 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	0.0003	0.0157	0.9011
WSF	0.0001	0.2040	0.8780
LIF	0.0026	0.0109	0.9328
WIF	<.0001	0.6699	0.7761
SFB	0.0002	0.9350	0.8753
IFB	0.0004	0.1696	0.8844
XHF	<.0001	0.0314	0.8066
LVF	0.0712	0.4960	0.9682
XSL	<.0001	0.0019	0.5594
SLV	<.0001	0.0144	0.6801
TLV	<.0001	0.0012	0.5486
XHP	<.0001	0.5811	0.8445
XHA	0.0238	0.7287	0.9544

B 22. L3 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	0.0129	0.0305	0.9486
WSF	<.0001	0.2470	0.8577
LIF	0.0001	<.0001	0.9028
WIF	<.0001	0.3035	0.8550
SFB	<.0001	0.3615	0.8540
IFB	0.0019	0.1295	0.9104
XHF	<.0001	0.0085	0.7443
LVF	0.3972	0.1333	0.9922
XSL	<.0001	0.0003	0.5096
SLV	<.0001	0.0020	0.5984
TLV	<.0001	0.0001	0.4694
XHP	<.0001	0.1003	0.8261
XHA	0.0544	0.6403	0.9659

B 23. L4 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	0.0116	0.0097	0.9457
WSF	<.0001	0.2755	0.8531
LIF	0.0070	0.0029	0.9396
WIF	0.0002	0.3608	0.8765
SFB	0.0005	0.0610	0.8937
IFB	0.0006	0.2121	0.8964
XHF	0.0805	0.1363	0.9725
LVF	0.3434	0.7516	0.9916
XSL	<.0001	0.0008	0.5958
SLV	<.0001	0.0077	0.5217
TLV	<.0001	0.0002	0.4426
XHP	<.0001	0.0633	0.7557
XHA	0.0026	0.7545	0.9184

B 24. L5 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	0.0163	0.0362	0.9386
WSF	0.0477	0.9210	0.9540
LIF	0.0003	0.3017	0.8580
WIF	<.0001	0.2324	0.8219
SFB	0.0100	0.0670	0.9243
IFB	0.0074	0.8479	0.9176
XHF	0.0013	0.1598	0.8874
LVF	0.0621	0.3746	0.9587
XSL	<.0001	0.0026	0.7284
SLV	<.0001	0.0027	0.5000
TLV	<.0001	0.0446	0.5190
XHP	<.0001	0.8298	0.7873
XHA	0.0014	0.2382	0.8849

B 25. Cervical, C3-C7 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	0.0002	0.0058	0.9733
WSF	<.0001	<.0001	0.9118
LIF	<.0001	<.0001	0.9616
WIF	<.0001	0.2591	0.9329
SFB	<.0001	0.0298	0.6902
IFB	<.0001	0.0069	0.7059
XHF	<.0001	0.0259	0.8163
LVF	<.0001	0.4303	0.9616
XSL	<.0001	0.0104	0.8292
SLV	<.0001	<.0001	0.7076
TLV	<.0001	0.2903	0.8948
XHP	<.0001	0.0704	0.6375
XHA	<.0001	0.5381	0.7241

B 26. Thoracic MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	<.0001	0.0459	0.9458
WSF	<.0001	0.0004	0.9249
LIF	<.0001	0.0052	0.9395
WIF	<.0001	0.1225	0.8973
SFB	<.0001	0.2395	0.8820
IFB	<.0001	0.1196	0.8390
XHF	<.0001	0.0547	0.9261
LVF	<.0001	0.2572	0.9825
XSL	<.0001	<.0001	0.7124
SLV	<.0001	0.0009	0.9070
TLV	<.0001	0.0488	0.8672
XHP	<.0001	0.8819	0.9306
XHA	<.0001	0.3975	0.9382

B 27. Lumbar MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	<.0001	<.0001	0.9495
WSF	<.0001	0.2020	0.9325
LIF	<.0001	<.0001	0.9261
WIF	<.0001	0.2008	0.8989
SFB	<.0001	0.1053	0.9651
IFB	0.0002	0.2634	0.9731
XHF	<.0001	0.0012	0.9227
LVF	0.8245	0.3894	0.9999
XSL	<.0001	<.0001	0.6656
SLV	<.0001	<.0001	0.6028
TLV	<.0001	<.0001	0.6044
XHP	<.0001	0.0462	0.8733
XHA	<.0001	0.8986	0.9466

B 28. C3-L5 MANOVA -- significance of variables by sex and age

	TYPE III SS		
VARIABLE	SEX	AGE	WILK'S LAMBDA
LSF	<.0001	0.0001	0.9744
WSF	<.0001	0.0002	0.9530
LIF	<.0001	<.0001	0.9681
WIF	<.0001	0.1077	0.9390
SFB	<.0001	0.7312	0.9647
IFB	<.0001	0.8377	0.9676
XHF	<.0001	0.0183	0.9710
LVF	<.0001	0.0923	0.9887
XSL	<.0001	<.0001	0.9103
SLV	<.0001	<.0001	0.9340
TLV	<.0001	0.0184	0.9477
XHP	<.0001	0.2700	0.9677
XHA	<.0001	0.8793	0.9807

B 29. Wilk's lambda values for sex and age by vertebra and vertebral grouping

VERTEBRA	SEX WILK'S LAMBDA	AGE WILK'S LAMBDA
C1	0.36593	0.89873
C2	0.30458	0.82446
C3	0.25706	0.77070
C4	0.67745	0.72522
C5	0.31717	0.78346
C6	0.32966	0.64100
C7	0.27929	0.76359
T1	0.28051	0.77852
T2	0.25434	0.75259
T3	0.29496	0.73830
T4	0.33705	0.76373
T5	0.73155	0.71222
T6	0.38153	0.82989
T7	0.42413	0.84738
T8	0.33477	0.81329
T9	0.36226	0.88742
T10	0.34491	0.77792
T11	0.30410	0.77238
T12	0.34157	0.84261
L1	0.34958	0.85326
L2	0.35870	0.79410
L3	0.26516	0.60989
L4	0.32845	0.66818
L5	0.37029	0.71684
C3-C7	0.35590	0.82430
T1-T12	0.53617	0.91763
L1-L5	0.39600	0.80153
C3-L5	0.61686	0.91555

Appendix C

Stepwise Selection

Contents of Appendix C

C 1. Stepwise selection for C1

	Partial R-square	Pr > F	Wilk's Lambda
IFB	0.4702	< .0001	0.52981726
XSL	0.2334	< .0001	0.40613277
WSF	0.0324	0.0704	0.39298753

C 2. Stepwise selection for C2

	Partial R-square	Pr > F	Wilk's Lambda
XSL	0.5997	< .0001	0.40032638
SFB	0.1482	< .0001	0.34100532
LSF	0.0523	0.0190	0.32317524

C 3. Stepwise selection for C3

	Partial R-square	Pr > F	Wilk's Lambda
XSL	0.4547	< .0001	0.54525339
XHP	0.2673	< .0001	0.39952265
TLV	0.0915	0.0032	0.3629536
LVF	0.0948	0.0028	0.32853993
SLV	0.0755	0.0084	0.30373286
XHA	0.0286	0.1111	0.295047

C 4. Stepwise selection for C4

	Partial R-square	Pr > F	Wilk's Lambda
XHP	0.4787	< .0001	0.52127628
IFB	0.1207	0.0009	0.45837025
XSL	0.0405	0.0617	0.4398258
WSF	0.0688	0.0147	0.40954882

C 5. Stepwise selection for C5

	Partial R-square	Pr > F	Wilk's Lambda
XSL	0.4273	< .0001	0.57265123
XHA	0.1969	< .0001	0.45991692
IFB	0.1261	0.0011	0.40193296
WSF	0.0351	0.0940	0.38782346

C 6. Stepwise selection for C6

	Partial R-square	Pr > F	Wilk's Lambda
IFB	0.4356	< .0001	0.56436079
XSL	0.2176	< .0001	0.4415742
XHP	0.0654	0.0162	0.41268976
SLV	0.0338	0.0881	0.39873009
XHA	0.0301	0.1101	0.38672416
remove XHP	0.0024	0.6509	0.38767382

C 7. Stepwise selection for C7

	Partial R-square	Pr > F	Wilk's Lambda
XSL	0.5203	< .0001	0.4796633
SFB	0.2070	< .0001	0.38035736
WSF	0.0809	0.0027	0.34957315
LIF	0.0772	0.0036	0.32260024
XHP	0.0630	0.0091	0.30228502
XHF	0.0329	0.0627	0.29233792

C 8. Stepwise selection for T1

	Partial R-square	Pr > F	Wilk's Lambda
XSL	0.5699	< .0001	0.43009111
IFB	0.2394	< .0001	0.32710854
XHP	0.0743	0.0033	0.30279019

C 9. Stepwise selection for T2

	Partial R-square	Pr > F	Wilk's Lambda
XSL	0.4823	< .0001	0.51769529
SFB	0.2519	< .0001	0.38729828
XHP	0.1793	< .0001	0.31784319
IFB	0.0592	0.0108	0.29902783
XHA	0.0315	0.0661	0.28960783
WSF	0.0362	0.0491	0.27907342

C 10. Stepwise selection for T3

	Partial R-square	Pr > F	Wilk's Lambda
XSL	0.4813	< .0001	0.51873607
SFB	0.2291	< .0001	0.39988487
XHP	0.0591	0.0105	0.37623578
TLV	0.0294	0.0744	0.36515889
LIF	0.0216	0.1288	0.35726259
WSF	0.0376	0.0453	0.34381771

C 11. Stepwise selection for T4

	Partial R-square	Pr > F	Wilk's Lambda
XSL	0.4328	< .0001	0.56723625
TLV	0.1600	< .0001	0.47645904
XHF	0.0796	0.0031	0.43852322
SFB	0.0374	0.0459	0.42212024
SLV	0.0438	0.0312	0.40361377

C 12. Stepwise selection for T5

	Partial R-square	Pr > F	Wilk's Lambda
XSL	0.4017	< .0001	0.59832515
XHF	0.1071	0.0005	0.53424448
SFB	0.0624	0.0091	0.5009103
WSF	0.1633	< .0001	0.41913128
TLV	0.0199	0.1496	0.41080812

C 13. Stepwise selection for T6

	Partial R-square	Pr > F	Wilk's Lambda
IFB	0.3893	< .0001	0.61072112
SLV	0.1974	< .0001	0.49015621
XHA	0.0942	0.0015	0.44400627

C 14. Stepwise selection for T7

	Partial R-square	Pr > F	Wilk's Lambda
TLV	0.3949	< .0001	0.60508289
IFB	0.1291	0.0002	0.52696236
XHP	0.0632	0.0121	0.49367301
XSL	0.0253	0.1175	0.48116852

C 15. Stepwise selection for T8

	Partial R-square	Pr > F	Wilk's Lambda
XSL	0.4398	< .0001	0.56015726
SFB	0.1313	0.0001	0.48663292
XHP	0.0795	0.0037	0.44794563
IFB	0.0227	0.1290	0.43779213
remove SFB	0.0115	0.2816	0.44287183
WIF	0.0292	0.0844	0.42994308
WSF	0.0287	0.0889	0.41761772

C 16. Stepwise selection for T9

	Partial R-square	Pr > F	Wilk's Lambda
XSL	0.4871	< .0001	0.51291127
SFB	0.1517	< .0001	0.43511712
XHA	0.0218	0.1486	0.425617

C 17. Stepwise selection for T10

	Partial R-square	Pr > F	Wilk's Lambda
XSL	0.4809	< .0001	0.51907983
IFB	0.2118	< .0001	0.40912763
LIF	0.0440	0.0363	0.39113919

C 18. Stepwise selection for T11

	Partial R-square	Pr > F	Wilk's Lambda
XSL	0.4765	< .0001	0.523502
IFB	0.2301	< .0001	0.40304125
SFB	0.0883	0.0027	0.63254585
XHP	0.0387	0.0508	0.64678324
LSF	0.0319	0.0783	0.65806346
TLV	0.0279	0.1020	0.66760545

C 19. Stepwise selection for T12

	Partial R-square	Pr > F	Wilk's Lambda
TLV	0.4696	< .0001	0.53040412
SFB	0.2387	< .0001	0.40379324
XSL	0.0461	0.0271	0.38517784
WIF	0.0293	0.0807	0.37388471

C 20. Stepwise selection for L1

	Partial R-square	Pr > F	Wilk's Lambda
TLV	0.5235	< .0001	0.47645326
SLV	0.0460	0.0273	0.45453536

C 21. Stepwise selection for L2

	Partial R-square	Pr > F	Wilk's Lambda
TLV	0.4514	< .0001	0.54860569
XSL	0.1026	0.0006	0.49231085
XHA	0.0271	0.0874	0.47899215
XHP	0.0368	0.0466	0.46134527
IFB	0.0354	0.0523	0.4450128

C 22. Stepwise selection for L3

	Partial R-square	Pr > F	Wilk's Lambda
TLV	0.5306	< .0001	0.46944559
XSL	0.1211	0.0002	0.41259803

C 23. Stepwise selection for L4

	Partial R-square	Pr > F	Wilk's Lambda
TLV	0.5574	< .0001	0.44256586
SLV	0.0569	0.0125	0.41738575
XHP	0.0203	0.1409	0.40889437
XHA	0.0311	0.0692	0.39617889
SFB	0.0274	0.0899	0.38532082
XSL	0.0250	0.1072	0.37569017

C 24. Stepwise selection for L5

	Partial R-square	Pr > F	Wilk's Lambda
SLV	0.5000	< .0001	0.50002126
TLV	0.1149	0.0014	0.44255058

C 25. Stepwise selection for Cervical, C3-C7

	Partial R-square	Pr > F	Wilk's Lambda
XHP	0.3606	< .0001	0.63942406
IFB	0.2593	< .0001	0.47363786
SLV	0.0630	< .0001	0.44377902
LVF	0.0873	< .0001	0.40503104
WIF	0.0217	0.0014	0.39623071
XSL	0.0240	0.0008	0.38673159
XHA	0.0136	0.0120	0.38146444
WSF	0.0117	0.0203	0.37702036
SFB	0.0114	0.0217	0.3727144

C 26. Stepwise selection for Thoracic

	Partial R-square	Pr > F	Wilk's Lambda
XSL	0.2916	< .0001	0.70839991
IFB	0.1839	< .0001	0.57812377
SFB	0.0110	0.0002	0.57178602
WIF	0.0116	0.0001	0.5651631
TLV	0.0084	0.001	0.56040129
SLV	0.0104	0.0003	0.55455923
LIF	0.0069	0.003	0.55073667
LSF	0.0024	0.0794	0.54940888
LVF	0.0022	0.0927	0.54819079
XHP	0.0026	0.0696	0.54677406

C 27. Stepwise selection for Lumbar

	Partial R-square	Pr > F	Wilk's Lambda
SLV	0.3972	< .0001	0.60276362
TLV	0.1076	< .0001	0.53793453
XHP	0.0770	< .0001	0.49652887
XHA	0.0585	< .0001	0.46747731
SFB	0.0182	0.0021	0.45897503
XSL	0.0277	0.0001	0.44624546
WSF	0.0137	0.0077	0.4401192
IFB	0.0043	0.1389	0.43824632
WIF	0.0047	0.1188	0.43617059

C 28. Stepwise selection for C3-L5

	Partial R-square	Pr > F	Wilk's Lambda
XSL	0.0908	< .0001	0.9091972
SFB	0.1640	< .0001	0.76006777
XHA	0.0617	< .0001	0.71313532
SLV	0.0478	< .0001	0.6790708
XHP	0.0222	< .0001	0.66402416
TLV	0.0294	< .0001	0.6445318
IFB	0.0090	< .0001	0.63870498
WSF	0.0111	< .0001	0.63161759
WIF	0.0021	0.0277	0.63026758
LVF	0.0028	0.012	0.62851282
LSF	0.0018	0.0434	0.62738117

Appendix D

Discriminant Function Analysis

Contents of Appendix D

D 1. Discriminant analysis equations for predicting sex from C1

	Number of Variables in Model		
	1	2	3
Inferior Facet Breadth (IFB)	0.8002	0.7076	0.7066
Maximum Sagittal Length (XSL)		0.6135	0.5983
Maximum Width Superior Facet (WSF)			0.3138
Constant	-37.8486	-61.6299	-64.6372
Sectioning Point	0	0	0
Calibration Sample			
Males Classified Correctly	78.9%	90.4%	88.2%
Females Classified Correctly	89.3%	94.4%	90.8%
Total Classified Correctly	84.1%	92.4%	89.5%

D 2. Discriminant analysis equations for predicting sex from C2

	Number of Variables in Model			
	1	1	2	3
Maximum Sagittal Length (XSL)	1.0241		0.8897	0.8988
Superior Facet Breadth (SFB)		0.8690	0.6606	0.5196
Maximum Length of Superior Facet (LSF)				0.6152
Constant	-51.5539	-40.8229	-75.7994	-80.7088
Sectioning Point	0	0	0	0
Calibration Sample				
Males Classified Correctly	92.4%	83.3%	92.5%	94.3%
Females Classified Correctly	85.7%	78.6%	89.3%	89.3%
Total Classified Correctly	89.1%	81.0%	90.9%	91.8%

D 3. Discriminant analysis equations for predicting sex from C3

	Number of Variables in Model					
	1	2	3	4	5	6
Maximum Sagittal Length (XSL)	0.8009	0.7147	0.7235	0.6790	0.5496	0.5384
Maximum Height of Posterior Vertebral Body (XHP)		1.6243	1.4059	1.6815	1.4926	1.1839
Transverse Length of Vertebral Body (TLV)			0.5435	0.6448	0.5393	0.5533
Length of Vertebral Foramen (LVF)				0.7848	1.1176	1.1097
Sagittal Length of Vertebral Body (SLV)					0.7212	0.6724
Maximum Height of Anterior Vertebral Body (XHA)						0.6332
Constant	-36.4116	-55.9695	-64.9272	-80.0160	-86.3169	-89.5109
Sectioning Point	0	0	0	0	0	0
Calibration Sample						
Males Classified Correctly	83.3%	85.7%	90.5%	95.2%	97.6%	92.9%
Females Classified Correctly	81.8%	87.0%	88.9%	88.9%	88.9%	90.7%
Total Classified Correctly	82.6%	86.4%	89.7%	92.1%	93.3%	91.8%

D 4. Discriminant analysis equations for predicting sex from C4

	Number of Variables in Model					
	1	1	1	2	3	4
Maximum Height of Posterior Vertebral Body (XHP)	1.7974			1.6060	1.3897	1.5162
Inferior Facet Breadth (IFB)		0.4713		0.3522	0.3140	0.5222
Maximum Sagittal Length (XSL)			0.5732		0.2539	0.3675
Maximum Width of Superior Facet (WSF)						-0.7686
Constant	-25.3478	-25.3708	-26.2350	-41.6243	-48.1816	-56.5149
Sectioning Point	0	0	0	0	0	0
Calibration Sample						
Males Classified Correctly	73.5%	81.3%	82.9%	81.3%	87.5%	87.5%
Females Classified Correctly	94.4%	68.5%	76.0%	85.2%	88.0%	88.0%
Total Classified Correctly	84.0%	74.9%	79.5%	83.2%	87.8%	87.8%

D 5. Discriminant analysis equations for predicting sex from C5

	Number of Variables in Model			
	1	2	3	4
Maximum Sagittal Length (XSL)	0.4994	0.4104	0.3650	0.4069
Maximum Height of Anterior Vertebral Body (XHA)		1.1140	1.0872	1.2365
Inferior Facet Breadth (IFB)			0.3910	0.4933
Maximum Width of Superior Facet (WSF)				-0.4128
Constant	-23.9848	-34.2133	-53.2526	-57.3839
Sectioning Point	0	0	0	0
Calibration Sample				
Males Classified Correctly	74.4%	76.7%	88.1%	88.1%
Females Classified Correctly	86.1%	88.1%	88.1%	85.7%
Total Classified Correctly	80.2%	82.4%	88.1%	86.9%

D 6. Discriminant analysis equations for predicting sex from C6

	Number of Variables in Model			
	1	2	3	4
Inferior Facet Breadth (IFB)	0.6340	0.6693	0.6401	0.6107
Maximum Sagittal Length (XSL)		0.3296	0.2493	0.1444
Sagittal Length of Vertebral Body (SLV)			0.3432	0.4636
Maximum Height of Anterior Vertebral Body (XHA)				0.8952
Constant	-34.4303	-53.9387	-54.4960	-61.2629
Sectioning Point	0	0	0	0
Calibration Sample				
Males Classified Correctly	76.5%	86.7%	84.1%	86.4%
Females Classified Correctly	84.6%	87.5%	89.4%	91.5%
Total Classified Correctly	80.5%	87.1%	86.7%	88.9%

D 7. Discriminant analysis equations for predicting sex from C7

	Number of Variables in Model					
	1	2	3	4	5	6
Maximum Sagittal Length (XSL)	0.5971	0.5028	0.5735	0.7079	0.6011	0.5919
Superior Facet Breadth (SFB)		0.5425	0.7767	0.8958	0.8550	0.8628
Maximum Width of Superior Facet (WSF)			-0.6944	-0.8075	-0.7197	-0.7366
Maximum Length of Inferior Facet (LIF)				-0.5643	-0.5730	-0.7076
Maximum Height of Posterior Vertebral Body (XHP)					1.0254	0.7981
Maximum Height of Facets (XHF)						0.3207
Constant	-35.7798	-59.4027	-65.9429	-71.6036	-79.9173	-82.9608
Sectioning Point	0	0	0	0	0	0
Calibration Sample						
Males Classified Correctly	87.5%	82.1%	87.5%	89.3%	92.7%	92.7%
Females Classified Correctly	86.0%	91.1%	92.9%	96.4%	96.4%	94.6%
Total Classified Correctly	86.7%	86.6%	90.2%	92.9%	94.6%	93.7%

D 8. Discriminant analysis equations for predicting sex from T1

	Number of Variables in Model			
	1	1	2	3
Maximum Sagittal Length (XSL)	0.6970		0.6467	0.5473
Inferior Facet Breadth (IFB)		0.6902	0.6265	0.5809
Maximum Height of Posterior Vertebral Body (XHP)				0.9911
Constant	-43.6528	-29.4511	-67.2255	-76.4889
Sectioning Point	0	0	0	0
Calibration Sample				
Males Classified Correctly	86.7%	86.7%	93.3%	91.5%
Females Classified Correctly	91.4%	84.5%	89.5%	91.2%
Total Classified Correctly	89.0%	85.6%	91.4%	91.4%

D 9. Discriminant analysis equations for predicting sex from T2

	Number of Variables in Model					
	1	2	3	4	5	6
Maximum Sagittal Length (XSL)	0.5383	0.4869	0.4100	0.3792	0.3866	0.4085
Superior Facet Breadth (SFB)		0.5666	0.5583	0.3638	0.3120	0.4804
Maximum Height of Facets (XHF)			1.1809	1.2779	2.1383	2.2411
Inferior Facet Breadth (IFB)				0.4048	0.4832	0.5363
Maximum Width of Superior Facet (WSF)					-0.8411	-0.9978
Maximum Length of Superior Facet (LSF)						-0.5488
Constant	-34.1042	-54.4831	-71.1633	-78.1126	-80.4114	-82.8189
Sectioning Point	0	0	0	0	0	0
Calibration Sample						
Males Classified Correctly	83.1%	89.8%	89.7%	87.9%	89.5%	91.2%
Females Classified Correctly	87.7%	87.7%	89.5%	89.5%	90.9%	89.1%
Total Classified Correctly	85.4%	88.8%	89.6%	88.7%	90.2%	90.2%

D 10. Discriminant analysis equations for predicting sex from T3

	Number of Variables in Model					
	1	2	3	4	5	6
Maximum Sagittal Length (XSL)	0.4779	0.4433	0.3556	0.3473	0.3433	0.3387
Superior Facet Breadth (SFB)		0.6189	0.6199	0.5166	0.4926	70.7510
Maximum Height of Anterior Vertebral Body (XHA)			0.7500	0.6765	0.6779	0.6707
Transverse Length of Vertebral Body (TLV)				0.2271	0.2238	0.2053
Maximum Width of Superior Facet (WSF)					0.4308	0.6562
Maximum Length of Inferior Facet (LIF)						-0.5653
Constant	-30.8197	-50.9263	-59.6913	-60.8024	-64.6805	-67.5514
Sectioning Point	0	0	0	0	0	0
Calibration Sample						
Males Classified Correctly	88.1%	88.1%	88.1%	88.1%	88.1%	89.8%
Females Classified Correctly	87.0%	90.7%	90.6%	86.8%	88.7%	88.7%
Total Classified Correctly	87.6%	89.4%	89.4%	87.5%	88.4%	89.3%

D 11. Discriminant analysis equations for predicting sex from T4

	Number of Variables in Model				
	1	2	3	4	5
Maximum Sagittal Length (XSL)	0.3740	0.3118	0.2609	0.2374	0.1564
Transverse Length of Vertebral Body (TLV)		0.4842	0.4590	0.3657	0.3605
Maximum Height of Facets (XHF)			0.4308	0.3879	0.2612
Superior Facet Breadth (SFB)				0.2770	0.3290
Sagittal Length of Vertebral Body (SLV)					0.4075
Constant	-24.1363	-34.1395	-44.5544	-48.3908	-50.3627
Sectioning Point	0	0	0	0	0
Calibration Sample					
Males Classified Correctly	84.8%	81.4%	77.6%	81.0%	87.9%
Females Classified Correctly	87.0%	87.0%	88.7%	88.7%	86.8%
Total Classified Correctly	85.9%	84.2%	83.1%	84.9%	87.4%

D 12. Discriminant analysis equations for predicting sex from T5

	Number of Variables in Model				
	1	2	3	4	5
Maximum Sagittal Length (XSL)	0.3752	0.3179	0.2455	0.2775	0.2311
Maximum Height of Facets (XHF)		0.4285	0.4242	0.6563	0.6384
Superior Facet Breadth (SFB)			0.3125	0.8291	0.7813
Maximum Width of Superior Facet (WSF)				-1.1390	-1.1369
Transverse Length of Vertebral Body (TLV)					0.2108
Constant	-24.0941	-34.9614	-40.5520	-54.6875	-55.7975
Sectioning Point	0	0	0	0	0
Calibration Sample					
Males Classified Correctly	79.7%	86.2%	81.0%	84.5%	82.8%
Females Classified Correctly	83.0%	83.0%	84.9%	86.8%	88.7%
Total Classified Correctly	81.3%	84.6%	83.0%	85.6%	85.7%

D 13. Discriminant analysis equations for predicting sex from T6

	Number of Variables in Model			
	1	1	2	3
Inferior Facet Breadth (IFB)	0.6363		0.5884	0.5457
Sagitttal Length of Vertebral Body (SLV)		0.6270	0.5648	0.5273
Maximum Height of Anterior Vertebral Body (XHA)				0.7417
Constant	-21.4261	-17.3214	-35.4610	-47.1282
Sectioning Point	0	0	0	0
Calibration Sample				
Males Classified Correctly	74.6%	81.4%	83.1%	86.4%
Females Classified Correctly	76.9%	76.9%	86.3%	82.4%
Total Classified Correctly	75.8%	79.1%	84.7%	84.4%

D 14. Discriminant analysis equations for predicting sex from T7

	Number of Variables in Model			
	1	2	3	4
Transverse Length of Vertebral Body (TLV)	0.6165	0.5277	0.4246	0.3000
Inferior Facet Breadth (IFB)		0.3804	0.3944	0.3537
Maximum Height of Posterior Vertebral Body (XHP)			0.5966	0.5448
Maximum Sagittal Length (XSL)				0.1334
Constant	-19.6301	-29.8778	-39.9250	-42.4030
Sectioning Point	0	0	0	0
Calibration Sample				
Males Classified Correctly	82.1%	80.0%	83.6%	85.5%
Females Classified Correctly	76.0%	84.0%	86.0%	87.2%
Total Classified Correctly	79.1%	82.0%	84.8%	86.3%

D 15. Discriminant analysis equations for predicting sex from T8

	Number of Variables in Model				
	1	2	3	4	5
Maximum Sagittal Length (XSL)	0.4054	0.3313	0.2337	0.2430	0.2416
Maximum Height of Posterior Vertebral Body (XHP)		0.7611	0.9201	0.9579	0.9579
Inferior Facet Breadth (IFB)			0.4169	0.6088	0.5958
Maximum Width of Inferior Facet (WIF)				-0.4993	-0.6672
Maximum Width of Superior Facet (WSF)					0.3957
Constant	-28.2247	-39.6739	-51.0667	-53.5668	-55.4066
Sectioning Point	0	0	0	0	0
Calibration Sample					
Males Classified Correctly	80.7%	84.2%	83.9%	85.7%	85.7%
Females Classified Correctly	78.9%	80.8%	88.0%	86.0%	84.0%
Total Classified Correctly	79.8%	82.5%	86.0%	85.9%	84.9%

D 16. Discriminant analysis equations for predicting sex from T9

	Number of Variables in Model		
	1	2	3
Maximum Sagittal Length (XSL)	0.4469	0.3618	0.3237
Superior Facet Breadth (SFB)		0.4806	0.4592
Maximum Height of Anterior Vertebral Body (XHA)			0.3359
Constant	-31.7147	-42.0932	-45.6721
Sectioning Point	0	0	0
Calibration Sample			
Males Classified Correctly	77.4%	84.6%	80.4%
Females Classified Correctly	84.0%	92.0%	87.8%
Total Classified Correctly	80.7%	88.3%	84.1%

D 17. Discriminant analysis equations for predicting sex from T10

	Number of Variables in Model		
	1	2	3
Maximum Sagittal Length (XSL)	0.4897	0.4288	0.4689
Inferior Facet Breadth (IFB)		0.4309	0.5312
Maximum Length of Inferior Facet (LIF)			-0.4557
Constant	-35.1177	-47.0977	-48.2100
Sectioning Point	0	0	0
Calibration Sample			
Males Classified Correctly	83.6%	81.1%	84.9%
Females Classified Correctly	82.0%	93.9%	91.8%
Total Classified Correctly	82.8%	87.5%	88.6%

D 18. Discriminant analysis equations for predicting sex from T11

	Number of Variables in Model					
	1	2	3	4	5	6
Maximum Sagittal Length (XSL)	0.4748	0.5083	0.4757	0.4165	0.4513	0.3692
Inferior Facet Breadth (IFB)		0.3881	0.3390	0.3700	0.3701	0.3686
Superior Facet Breadth (SFB)			0.2863	0.2757	0.3766	0.3539
Maximum Height of Posterior Vertebral Body (XHP)				0.4479	0.4280	0.3676
Maximum Length of Superior Facet (LSF)					-0.3934	-0.4240
Transverse Length of Vertebral Body (TLV)						0.2126
Constant	-34.2244	-49.9946	-56.5037	-64.4029	-65.5156	-65.6117
Sectioning Point	0	0	0	0	0	0
Calibration Sample						
Males Classified Correctly	85.5%	87.0%	83.0%	86.8%	84.9%	84.6%
Females Classified Correctly	84.0%	90.0%	98.0%	96.0%	90.0%	94.0%
Total Classified Correctly	84.7%	88.5%	90.5%	91.4%	87.5%	89.3%

D 19. Discriminant analysis equations for predicting sex from T12

	Number of Variables in Model			
	1	2	3	4
Transverse Length of Vertebral Body (TLV)	0.5663	0.5849	0.4384	0.4397
Superior Facet Breadth (SFB)		0.4225	0.4302	0.4724
Maximum Sagittal Length (XSL)			0.2123	0.2644
Maximum Width of Inferior Facet (WIF)				-0.4155
Constant	-24.9916	-40.4815	-50.2337	-51.3537
Sectioning Point	0	0	0	0
Calibration Sample				
Males Classified Correctly	81.0%	86.0%	82.1%	83.9%
Females Classified Correctly	85.2%	90.7%	92.6%	92.6%
Total Classified Correctly	83.1%	88.4%	87.4%	88.3%

D 20. Discriminant analysis equations for predicting sex from L1

	Number of Variables in Model		
	1	1	2
Transverse Length of Vertebral Body (TLV)	0.6024		0.4913
Sagittal Length of Vertebral Body (SLV)		0.5471	0.2194
Constant	-27.9014	-18.1490	-30.0348
Sectioning Point	0	0	0
Calibration Sample			
Males Classified Correctly	80.0%	74.6%	81.5%
Females Classified Correctly	87.5%	83.9%	87.5%
Total Classified Correctly	83.8%	79.2%	84.5%

D 21. Discriminant analysis equations for predicting sex from L2

	Number of Variables in Model				
	1	2	3	4	5
Transverse Length of Vertebral Body (TLV)	0.5464	0.3593	0.3860	0.3333	0.3047
Maximum Sagittal Length (XSL)		0.2609	0.3003	0.3266	0.3387
Maximum Height of Anterior Vertebral Body (XHA)			-0.2928	-0.5131	-0.6068
Maximum Height of Posterior Vertebral Body (XHP)				0.4510	0.4860
Inferior Facet Breadth (IFB)					0.1346
Constant	-26.4651	-39.5223	-35.9244	-42.4633	-44.7447
Sectioning Point	0	0	0	0	0
Calibration Sample					
Males Classified Correctly	76.8%	82.1%	85.7%	82.1%	83.9%
Females Classified Correctly	85.7%	83.6%	81.8%	85.5%	87.3%
Total Classified Correctly	81.3%	82.9%	83.8%	83.8%	85.6%

D 22. Discriminant analysis equations for predicting sex from L3

	Number of Variables in Model		
	1	1	2
Transverse Length of Vertebral Body (TLV)	0.6948		0.4987
Maximum Sagittal Length (XSL)		0.4534	0.3016
Constant	-35.2181	-39.0508	-51.2477
Sectioning Point	0	0	0
Calibration Sample			
Males Classified Correctly	82.5%	76.8%	85.7%
Females Classified Correctly	83.0%	88.9%	86.5%
Total Classified Correctly	82.7%	82.8%	86.1%

D 23. Discriminant analysis equations for predicting sex from L4

	Number of Variables in Model					
	1	2	3	4	5	6
Transverse Length of Vertebral Body (TLV)	0.7209	0.5505	0.5194	0.5355	0.4861	0.4398
Sagittal Length of Vertebral Body (SLV)		0.3667	0.3422	0.4023	0.4119	0.3205
Maximum Height of Posterior Vertebral Body (XHP)			0.2587	0.4483	0.5944	0.5077
Maximum Height of Anterior Vertebral Body (XHA)				-0.4450	-0.5489	-0.6382
Superior Facet Breadth (SFB)					0.1212	0.1392
Maximum Sagittal Length (XSL)						0.1507
Constant	-37.7874	-41.7480	-46.3256	-41.5502	-44.9398	-47.6894
Sectioning Point	0	0	0	0	0	0
Calibration Sample						
Males Classified Correctly	83.1%	87.9%	86.2%	87.9%	87.9%	87.7%
Females Classified Correctly	87.3%	89.1%	87.0%	87.0%	92.6%	88.7%
Total Classified Correctly	85.2%	88.5%	86.6%	87.5%	90.3%	88.2%

D 24. Discriminant analysis equations for predicting sex from L5

	Number of Variables in Model		
	1	1	2
Sagittal Length of Vertebral Body (SLV)	0.7783		0.5490
Transverse Length of Vertebral Body (TLV)		0.5137	0.3319
Constant	-27.0554	-27.3784	-36.7841
Sectioning Point	0	0	0
Calibration Sample			
Males Classified Correctly	85.5%	86.8%	88.5%
Females Classified Correctly	83.0%	87.0%	87.0%
Total Classified Correctly	84.2%	86.9%	87.7%

D 25. Discriminant analysis equations for predicting sex from Cervical, C3-C7

	Number of Variables in Model					
	1	2	3	4	5	6
Maximum Height of Posterior Vertebral Body (XHP)	1.3077	1.4605	1.3080	1.3374	14.1897	1.3847
Inferior Facet Breadth (IFB)		0.3908	0.3505	0.3101	4.1343	0.4713
Sagittal Length of Vertebral B ody (SLV)			0.4038	0.6162	5.6053	0.4921
Length of Vertebral Foramen (LVF)				0.6995	10.8672	0.6062
Maximum Width of Inferior Facet (WIF)					-1.8588	-0.4084
Maximum Sagittal Length (XSL)						0.1103
Maximum Height of Anterior Vertebral Body (XHA)						
Maximum Width of Superior Facet (WSF)						
Superior Facet Breadth (SFB)						
Constant	-18.7774	-41.7096	-44.6254	-56.5044	-58.1925	-62.0125
Sectioning Point	0	0	0	0	0	0
Calibration Sample						
Males Classified Correctly	72.6%	82.5%	86.4%	89.6%	90.8%	91.5%
Females Classified Correctly	83.1%	86.1%	86.5%	89.4%	89.4%	89.1%
Total Classified Correctly	77.8%	84.3%	86.4%	89.5%	90.1%	90.3%

D 26 cont'd. Discriminant analysis equations for predicting sex from Cervical, C3-C7

	7	8	9
Maximum Height of Posterior Vertebral Body (XHP)	1.0366	1.0901	1.0538
Inferior Facet Breadth (IFB)	0.4800	0.4983	0.4205
Sagittal Length of Vertebral B ody (SLV)	0.5099	0.5112	0.5100
Length of Vertebral Foramen (LVF)	0.5952	0.6077	0.6335
Maximum Width of Inferior Facet (WIF)	-0.4186	-0.3660	-0.3620
Maximum Sagittal Length (XSL)	0.1060	0.1301	0.0997
Maximum Height of Anterior Vertebral Body (XHA)	0.4264	0.4329	0.4789
Maximum Width of Superior Facet (WSF)		-0.2394	-0.3600
Superior Facet Breadth (SFB)			0.1753
Constant	-63.0879	-68.8841	-66.3233
Sectioning Point	0	0	0
Calibration Sample			
Males Classified Correctly	91.9%	91.5%	89.2%
Females Classified Correctly	89.9%	90.3%	90.3%
Total Classified Correctly	90.9%	90.9%	89.7%

D 27. Discriminant analysis equations for predicting sex from Thoracic

	Number of Variables in Model					
	1	2	3	4	5	6
Maximum Sagittal Length (XSL)	0.2245	0.2593	0.2609	0.2717	0.3176	0.2748
Inferior Facet Breadth (IFB)		0.2628	0.2063	0.2718	0.2543	0.2337
Superior Facet Breadth (SFB)			0.0668	0.0751	0.0976	0.1572
Maximum Width of Inferior Facet (WIF)				-0.2350	-0.2337	-0.2265
Transverse Length of Vertebral B ody (TLV)					-0.0689	-0.1075
Sagittal Length of Vertebral B ody (SLV)						0.1095
Maximum Length of Inferior Facet (LIF)						
Maximum Length of Superior Facet (LSF)						
Length of Vertebral Foramen (LVF)						
Maximum Height of Posterior Vertebral Body (XHP)						
Constant	-15.1466	-26.8271	-27.3512	-27.9623	-28.9195	-29.1621
Sectioning Point	0	0	0	0	0	0
Calibration Sample						
Males Classified Correctly	72.0%	80.3%	80.2%	80.9%	81.1%	81.1%
Females Classified Correctly	74.6%	81.2%	81.1%	81.8%	83.6%	83.1%
Total Classified Correctly	73.3%	81.0%	80.7%	81.4%	82.3%	82.1%

D 28 cont'd. Discriminant analysis equations for predicting sex from Thoracic

	7	8	9	10
Maximum Sagittal Length (XSL)	0.2717	0.2690	0.2775	0.2769
Inferior Facet Breadth (IFB)	0.2679	0.2728	0.2735	0.2809
Superior Facet Breadth (SFB)	0.1455	0.1371	0.1363	0.1406
Maximum Width of Inferior Facet (WIF)	-0.3157	-0.3182	-0.3372	-0.3244
Transverse Length of Vertebral Body (TLV)	-0.1184	-0.1174	-0.1160	-0.1387
Sagittal Length of Vertebral Body (SLV)	0.1112	0.1129	0.1109	0.0855
Maximum Length of Inferior Facet (LIF)	0.1586	0.1302	0.1433	0.1246
Maximum Length of Superior Facet (LSF)		0.0869	0.0926	0.0864
Length of Vertebral Foramen (LVF)			-0.0957	-0.1230
Maximum Height of Posterior Vertebral Body (XHP)				0.1030
Constant	-30.2675	-30.6830	-29.7661	-30.3482
Sectioning Point	0	0	0	0
Calibration Sample				
Males Classified Correctly	80.4%	81.3%	80.7%	81.4%
Females Classified Correctly	83.2%	83.6%	84.2%	84.3%
Total Classified Correctly	81.8%	82.4%	82.4%	82.9%

D 29. Discriminant analysis equations for predicting sex from Lumbar

	Number of Variables in Model					
	1	2	3	4	5	6
Sagittal Length of Vertebral Body (SLV)	0.5858	0.3867	0.3084	0.3137	0.3356	0.2218
Transverse Length of Vertebral Body (TLV)		0.2552	0.3054	0.4285	0.3804	0.3514
Maximum Height of Posterior Vertebral Body (XHP)			0.3741	0.4638	0.6183	0.5802
Maximum Height of Anterior Vertebral Body (XHA)				-0.4358	-0.5442	-0.6276
Superior Facet Breadth (SFB)					0.0830	0.1244
Maximum Sagittal Length (XSL)						0.1414
Maximum Width of Superior Facet (WSF)						
Inferior Facet Breadth (IFB)						
Maximum Width of Inferior Facet (WIF)						
Constant	-20.2255	-26.1576	-36.3616	-32.8375	-35.3697	-39.4615
Sectioning Point	0	0	0	0	0	0
Calibration Sample						
Males Classified Correctly	81.1%	81.2%	84.8%	84.4%	85.8%	86.6%
Females Classified Correctly	78.8%	81.6%	83.0%	85.2%	85.2%	87.2%
Total Classified Correctly	80.0%	81.4%	83.9%	84.8%	85.5%	86.9%

D 30 cont'd. Discriminant analysis equations for predicting sex from Lumbar

	7	8	9
Sagittal Length of Vertebral Body (SLV)	0.2098	0.2155	0.2156
Transverse Length of Vertebral Body (TLV)	0.3845	0.4002	0.3992
Maximum Height of Posterior Vertebral Body (XHP)	0.5439	0.5026	0.5072
Maximum Height of Anterior Vertebral Body (XHA)	-0.5824	-0.5473	-0.5523
Superior Facet Breadth (SFB)	0.1460	0.1847	0.1915
Maximum Sagittal Length (XSL)	0.1647	0.1587	0.1493
Maximum Width of Superior Facet (WSF)	-0.1834	-0.1697	-0.2142
Inferior Facet Breadth (IFB)		-0.0455	-0.0661
Maximum Width of Inferior Facet (WIF)			0.1493
Constant	-41.0591	-41.2448	-41.2708
Sectioning Point	0	0	0
Calibration Sample			
Males Classified Correctly	87.4%	87.3%	87.3%
Females Classified Correctly	87.6%	87.9%	87.2%
Total Classified Correctly	87.5%	87.6%	87.2%

D 31. Discriminant analysis equations for predicting sex from C3-L5

	Number of Variables in Model					
	1	2	3	4	5	6
Maximum Sagittal Length (XSL)	0.0524	0.1081	0.2015	0.1569	0.1429	0.1880
Superior Facet Breadth (SFB)		0.1301	0.1260	0.1509	0.1775	0.2170
Maximum Height of Anterior Vertebral Body (XHA)			-0.2349	-0.3163	-0.4601	-0.3697
Sagittal Length of Vertebral Body (SLV)				0.1754	0.1422	0.1650
Maximum Height of Posterior Vertebral Body (XHP)					0.2627	0.3284
Transverse Length of Vertebral Body (TLV)						-0.1342
Inferior Facet Breadth (IFB)						
Maximum Width of Superior Facet (WSF)						
Maximum Width of Inferior Facet (WIF)						
Length of Vertebral Foramen (LVF)						
Maximum Length of Superior Facet (LSF)						
Constant	-3.5462	-12.4574	-13.7955	-14.7738	-16.6998	-20.3941
Sectioning Point	0	0	0	0	0	0
Calibration Sample						
Males Classified Correctly	65.5%	67.5%	72.5%	72.7%	74.3%	76.2%
Females Classified Correctly	63.3%	73.1%	75.4%	76.9%	77.2%	79.0%
Total Classified Correctly	64.4%	70.3%	74.0%	74.8%	75.7%	77.6%

D 32 cont’d. Discriminant analysis equations for predicting sex from C3-L5

	7	8	9	10	11
Maximum Sagittal Length (XSL)	0.2029	0.2216	0.2299	0.2362	0.2391
Superior Facet Breadth (SFB)	0.1642	0.1868	0.1838	0.1876	0.1923
Maximum Height of Anterior Vertebral Body (XHA)	-0.4495	-0.4267	-0.4330	-0.4253	-0.4350
Sagittal Length of Vertebral Body (SLV)	0.1274	0.1070	0.1018	0.0945	0.0957
Maximum Height of Posterior Vertebral Body (XHP)	0.4245	0.4094	0.4115	0.4312	0.4283
Transverse Length of Vertebral Body (TLV)	-0.1335	-0.1180	-0.1174	-0.1199	-0.1225
Inferior Facet Breadth (IFB)	0.0641	0.0745	0.0907	0.0952	0.0920
Maximum Width of Superior Facet (WSF)		-0.1533	-0.1299	-0.1416	-0.1697
Maximum Width of Inferior Facet (WIF)			-0.0825	-0.0967	-0.0990
Length of Vertebral Foramen (LVF)				-0.0934	-0.0975
Maximum Length of Superior Facet (LSF)					0.0583
Constant	-21.3164	-22.0398	-22.1748	-21.4591	-21.6648
Sectioning Point	0	0	0	0	0
Calibration Sample					
Males Classified Correctly	76.4%	76.4%	76.4%	76.9%	77.1%
Females Classified Correctly	78.4%	79.3%	79.2%	79.8%	80.0%
Total Classified Correctly	77.4%	77.9%	77.8%	78.3%	78.5%

Vita

Amanda Suzanne Allbright was born in North Little Rock, Arkansas on September 24, 1981. She moved around several times as a young child but grew up in Germantown, TN and graduated from Germantown High School in 2000. Amanda attended the University of Tennessee in Knoxville and graduated Magna Cum Laude in May 2004 with a Bachelor of Arts degree in anthropology with a minor in biology and a Bachelor of Arts degree in sociology with a concentration in criminal justice. She continued her education at the University of Tennessee by starting the masters program in anthropology. Amanda Allbright received her M.A. in Anthropology from the University of Tennessee, Knoxville in December 2007.