To the Graduate Council:

I am submitting herewith a thesis written by Gwendolyn M. Haugen entitled "The Cervical Spine: Race and Sex Differences." I have examined the final copy of this thesis for form and content and recommended that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Anthropology.

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THE CERVICAL SPINE:
RACE AND SEX DIFFERENCES

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Gwendolyn M. Haugen

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ABSTRACT

This study examines the possible correlation of cervical vertebrae (C2-C7) gross morphological and metric variation with race and sex. Developmental and normal anatomy of the cervical vertebrae are investigated to pinpoint any functional reason associated with this variability. The 174 individuals comprising the pooled data set consisted of black and white males and females from the William M. Bass Collection and the Terry Anatomical Collection. Five measurements and one spinous process type classification were collected on each cervical vertebra (C2-C7). A series of multivariate and discriminant statistical tests were performed on the measurement data to determine whether significant variation exists with respect to race and sex. The typological data were subjected to Chi^2 tests to estimate the strength of the relationships between spinous process gross morphological type categorizations and race.

Results of these tests indicate discernible size and gross morphological differences between cervical vertebrae relative to race and/or sex. Such measurable differences were discriminated with moderate to high accuracy for race and sex: further, group classifications were found to be low to moderate. The strength of the relationship between spinous process gross morphological types and race was found to be significant at the C3, C4, and C5 level. No conclusions were reached as to the cause and function of this variation.

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CHAPTER 1

OVERVIEW

Introduction

This research deals with both gross morphological and metric variation of the cervical vertebrae and their relationship to race and sex, a subject which has not as yet received much study attention. Skeletal variation (both gross morphological and metric) linked to sex and/or racial affinity has been researched by a plethora of investigators, but the spine has been either only quietly studied by a hand-full of scientists or ignored all together. The great number of structural variations presented in the cervical spine are one of the reasons for lack of interest in this area. These variations may or may not be of any pathological significance. Nonetheless, this weak normal-anatomical foundation of the cervical spine has been researched by a few individuals during the past few decades in detail (Bailey, 1974; Jackson, 1978; Junghanns, 1971; Sherk and Parke, 1983). The results of these limited studies seem to point to an underlying genetic foundation for these variations and not, as has been suggested by many researchers, merely indicate random development.

Because both metric and nonmetric traits are determined by the growth and development of the soft tissues and functional spaces of

the skeleton that act both locally and on a broader scale, it will first be necessary to gain a thorough understanding of the underlying anatomy of the cervical spine in order to completely grasp the uniqueness of the morphological form and variation noted therein (Cheverud et al., 1979; Saunders, 1989).

Developmental Anatomy of the Cervical Spine

In order to study the cervical spine, an understanding of the unique developmental anatomy of the region is needed. Each end result is preceded by a definite course of developmental events in the body (Arey, 1966). By examining the formation process of the cervical vertebrae, a more thorough picture is revealed of the processes that shape their morphology and the functionality connected with their configuration.

There are four main stages in the development of the cervical spine: (1) the development of the notochord; (2) the laying down of the mesenchymatous and cartilaginous precursors; (3) ossification; and (4) the growth of the vertebrae. These stages are not mutually exclusive, as growth and development is a continuing process. As such, some degree of overlap between the stages is seen (Bailey, 1974).

The notochord, unsegmented, flexible, and rodlike, appears at about the third week of embryonic life. It provides the important framework around which the vertebral column will be formed. The

notochord will eventually be completely enveloped and exist only in the nucleus pulposus of the itervertebral discs and the apical and alar ligaments of the axis (Bailey, 1974; Ehrenhaft, 1943).

Bilateral segmentation of the paraxial mesoderm begins at about twenty-one days in the occipital area and proceeds caudally until completion near the end of the first month. There is no consensus of opinion on the number of somite pairs produced. Generally, the numbers range from 41-44 pairs which are separated from each other by intersegmental septa. From each somite, there develops a dermatome, a myotome, and a sclerotome. The cells of the sclerotome migrate medially towards the notochord where the perichordal sheath forms a complete but transient septum dividing the mesenchymal provertebral bodies into right and left halves (Bailey, 1974; Ehrenhaft, 1943; Sherk and Parke, 1983).

At 5 to 6 weeks, resegmentation of the embryo occurs, and the somites become vertebrae. During resegmentation, the right and left halves of the somites at each level fuse across the midline. The notochord is incorporated into the vertebrae during this fusion process. The mesenchymal cells present migrate to the midportion of the somite where they appear as a darkly stained cluster. This occurs near a cleft known as the fissure of Von Ebner. As this fissure widens, the clustered mesenchymal cells give rise to an intervertebral disc. The primitive vertebral body is formed at the same time through a process in which the caudal half of one somite fuses with the cranial half of the adjacent somite. Cells from the

vertebral body migrate dorsally over the neural tube to form the vertebral arches and ventrally to form the costal processes or ribs. At the conclusion of the resegmentation process, the embryo becomes a fetus (Sherk and Parke, 1983). According to Bailey (1974), any symmetrical or asymmetrical disorders of segmentation must arise in this early stage of development since no further changes in position occur during chondrification and ossification.

It is in this fetal phase of development that the mesenchymal anlage of the vertebrae undergo chondrogenesis and osteogenesis. The vertebral shape and fundamental structure do not change, but a new tissue matrix is acquired and the vertebrae grow considerably. The process of chondrification begins at the cervico-thoracic level and extends cranially and caudally along the length of the vertebral column. Most researchers suggest that chondrification begins in two centers on each side of the midline in the vertebral bodies. In most individuals, these centers unite rapidly. The change in consistency from the soft mesenchymal tissue to the hard cartilaginous tissue forces the notochordal tissue out of the vertebral body and into the intervertebral disc space. The notochordal cells remain there and form the nucleus pulposus. Chondrification also occurs in each neural arch and in each costal process. The chondrification centers of the dorsal arches and costal processes merge; thus, cartilaginous tissue replaces the mesenchymal tissue completely in all of the arches. Chondrification then extends down the arches into the substance of the vertebral body, and by the eighth week of development, fusion

has taken place between the cartilaginous arches and the body. The cartilaginous vertebral body is therefore the true foundation for the development of the osseous vertebral body (Bailey, 1974; Ehrenhaft, 1943; Sherk and Parke, 1983).

The developmental processes for the axis and atlas are slightly different due to their unique configuration. The vertebral body of C1 does not form a distinct centrum. Instead, it results from the fusion of the caudal portion of the C1 somite with the cranial portion of the C2 somite. This fusion produces the odontoid process which is incorporated into the vertebral body of C2 and represents the centrum of the atlas caudally displaced. A dense band of tissue, known as the hypochordal bow, extends ventrally around the vertebra and gives rise to the anterior arch of the atlas at the C1 level. The hypochordal bow develops at each subsequent vertebral level but is much less pronounced caudally. It will eventually give rise to the anterior longitudinal ligament (ALL), which overlies the anterior aspect of each vertebral body (Sherk and Parke, 1983).

The ossification of C3-C7 follows the same general pattern, while C1 and C2 deviate somewhat. Therefore, the ossification pattern of C3-C7 will be addressed first, and that of C1 and C2 will be addressed second. Ossification of the vertebral column begins during the 2nd month starting in the lower thoracic area and extending rapidly cranially. By the 4th month, ossification centers are present in all cervical vertebral bodies. The process of ossification begins in the vertebrae (C3-C7) from three primary ossification centers (ossific

nuclei), one in the vertebral body and one in each neural arch respectively. These nuclei increase in size and occupy an increasing percentage of the matrix of the vertebra. Where the ossific nuclei of the vertebral arches join the ossific nuclei of the vertebral body, a synchondrosis develops termed the neurocentral joint. Therefore, at the time of birth C3-C7 are characterized by three ossific components: (1) two neural arches that have not yet fused together posteriorly (this occurs during the first year of life); and (2) a centrum which has not yet fused with the neural arches (Bailey, 1974; Ehrenhaft, 1943; Junghanns, 1971; Sherk and Parke, 1983).

The atlas has only two primary ossific nuclei which correspond to the neural arch centers of C3-C7. The axis ossifies from five primary nuclei: (1) the three aforementioned for C3-C7 which develop in a similar manner; and (2) the two that occur in the odontoid process. The paired ossific nuclei of the odontoid process fuse across the midline forming a single ossific structure at about the time of birth (Bailey, 1974; Ehrenhaft, 1943; Junghanns, 1971; Sherk and Parke, 1983).

The vertebrae continue to ossify from the cartilaginous models that formed in the mesenchymal anlage from the time of birth until adulthood. Secondary ossification nuclei appear in the vertebrae after birth and are variable in number depending on the vertebra. Variation in the ossification of the atlas is common. The lateral masses of the vertebra have ossified at the time of birth, and ossification proceeds posteriorly into the arches. Full closure of the

atlantal ring is usually completed by the 3rd or 4th year. One secondary ossification center forms in the anterior arch toward the end of the 1st year. This center extends into and fuses with the anterior end of each upper articular facet between the 6th and 9th year. Interestingly, this secondary site is considered the phyletic remnant of the hypochordal bar (intercentrum) of lower vertebrates (Bailey, 1974; Sherk and Parke, 1983).

The odontoid process begins to fuse with the ossific nucleus of the axis at the age of 4 years. The fusion begins circumferentially and is almost always complete by the age of 7 years. However, almost one-third of normal adults have a remnant of cartilaginous tissue between the odontoid and the C2 vertebral body. A secondary ossification center develops at the tip of the odontoid process during the 2nd year and fuses with the main portion of the odontoid by about the 12th year. In addition to the development of the odontoid process, the vertebral body and arches of C2 develop in a manner similar to that seen in C3-C7. This aspect of ossification is discussed below (Bailey, 1974; Ehrenhaft, 1943; Sherk and Parke, 1983).

Since the ossification of the vertebral bodies and arches for C2-C7 share similar patterns, they will be discussed concurrently. The arch ossific nucleus at each vertebral level spreads dorsally from its point of origin at the base of the transverse process into the arch and ventrally into the pedicle. The secondary ossific nuclei sites usually appear by late childhood. These sites consists of rings of hard cortical bone that develop about the margins of the vertebral bodies.

The unossified central portion of the rings functions as an intervertebral disc anchor after formation of the site is complete (Bailey, 1974; Junghanns, 1971; Sherk and Parke, 1983). The exact age when the secondary ring ossification centers fuse to the primary centers is murky at best. Sherk and Parke (1983) find the age of fusion to be between 15 to 16 years of age, while Bailey's (1974) research suggests fusion occurs in the early part of the third decade. The roentgenogram research of Junghanns (1971) provides evidence that the vertebral ring fuses with the body beginning at the age of 14 or 15. Moreover, he states that this process commences in several places simultaneously, and that osseous bridges are formed which slowly broaden replacing the last remnants of the cartilaginous rim. No age range is given by Junghanns (1971) for completion of this process. Buikstra and Gordon's (1980) research, which describes this process as "epiphyseal ring fusion", yielded a completion age of 25 years for their sample of black females. Their research will be discussed further in the *Variation due to Age* section.

Secondary centers also form at the tips of the spinous and transverse processes at about the age of 16 (Bailey, 1974; Junghanns, 1971; Sherk and Parke, 1983). According to Bailey (1974), the secondary ossification centers at the tips of the spinous processes can either be paired or singular coinciding with a bifid or non-bifid spinous process respectively. Junghanns (1971) finds that the cervical vertebral bodies are "peculiar" in that two of these additional ossification centers occur at the tip of the spinous process

thus causing the split appearance of the spinous process to be formed. In contrast, Sherk and Parke (1983) make reference to singular secondary ossification centers at the tips of the spinous processes. They bypass the issue of the development of bifid spines all together and only later mention that C2-C5 are usually bifid.

Normal Adult Anatomy of the Cervical Spine

A thorough knowledge of the normal anatomical features of this region is required in order to fully understand the cause and effect relationship between the vertebrae and the associated overlying soft tissue. This section will discuss the fully developed spine and a portion of the ligamentous tissues of the region. The third through the sixth cervical vertebrae (C3-C6) are considered "typical", while C1, C2, and C7 are "modified", and thus will be dealt with separately in this section. (England, 1971).

Characteristically, vertebrae are composed of an anteriorly placed body and a posterior neural arch formed from two growth centers; each forms one-half of the arch, and they join at the midline as an elongation, the spinous process. The vertebral body is a roughly cylindrical mass of cancellous bone contained in a thin shell of cortical bone. Its superior surface is concave and lipped by a raised edge of bone on its margin, the vertebral rim. It is correspondingly convex on its inferior surface, although the antero-inferior portion of the vertebral body tends to project downward over the antero-

superior surface of the vertebra below it. The postero-superior portion of the bodies has a cephalic flare forming the uncovertebral joint of Luschka (or Von Luschka), situated just antero-medially to the transverse foramina. In the newborn, these ridges are flat and only later do they slowly develop cranially. This gives the superior surface the shape of a saddle. These joints vary considerably in the size and shape of the articulations from one individual to another and their depth appears to gradually decrease caudally. Their main purpose is to prevent anterior slipping of the bodies on one other. The vertebral foramen, which houses and protects the spinal cord, is characteristically large and triangular in shape. It is in the cervical region where the spinal cord is of the greatest diameter. The pedicles arise from the cervical vertebrae midway between the superior and inferior articular facets. They are short and blunt projecting laterally. The transverse foramen which permit passage of the vertebral artery and vein, unique to the cervical spine, are formed from the thin costal processes anteriorly and the transverse processes posteriorly. These are joined by a bridge of bone, ultimately forming the transverse foramen. Both the costal process and the transverse process are prolonged as anterior and posterior tubercles. The size and shape of the transverse foramen is largely determined by the veins and arteries which occupy this space. In some instances a spicule of bone divides the foramen, thus producing two foramina. The spinous processes project posteriorly from the junction of the two laminae, and are attachment sites for the

ligamentum nuchae and muscles of the posterior neck. They slope downward and may overlap the adjacent distal spinous process. Size, strength, and downward inclination vary between individuals. Most researchers maintain that the spinous processes are usually bifid with the exception of C7 which is usually non-bifid (Bailey, 1974; Bass, 1987; Bateman, 1978; England, 1971; Gray, 1989; Jackson, 1978; Junghanns, 1971; Sherk and Parke, 1983; Tortora, 1989; White and Pajabi, 1990).

This vertebral design is approximately the same from C3-L5 (excluding the unique atlas and axis), but the size and mass of the vertebrae increase caudally as a biomechanical adaptation to the progressively increasing compression loads to which they are subjected (Gilad and Nissan, 1986; Jochumsen, 1970; White and Pajabi, 1990).

The atlas, C1, is so named for its chief function, that of supporting the globe of the head. This bone is peculiar in that it has neither a body nor a spinous process. As discussed previously, its body is displaced and incorporated into the odontoid process of C2, the axis. The atlas is ring-like, and consists of an anterior arch, a posterior arch and two lateral masses. The anterior arch forms about one-fifth of the ring and is produced by the parts corresponding to the pedicles joining in front. The anterior surface is convex; posteriorly it is concave and marked by a smooth, oval or circular facet for articulation with the odontoid process of C2. The posterior arch forms about two-fifths of the circumference of the bone. It

terminates behind a tubercle which is the rudiment of a spinous process. Completing the ring are the lateral masses, which support the weight of the head, and are the most bulky and solid portions of the axis. They consist of two articulating processes on the superior surface and two on the inferior surface of the bone. The two superior processes are large in size, oval and concave. They are directed upward, inward, and slightly backward forming a cup-shaped housing for articulation with the corresponding condyle of the occipital bone. This formation allows for the nodding movements of the head. The inferior articular processes are circular in form, flattened or slightly concave, and directed downward and inward. These processes articulate with the axis and allow for the rotation movements of the head. The transverse processes are of large size, projecting directly outward and downward from the lateral masses. These processes serve as the insertion sites for muscles which assist in the rotation of the head. They are long and contain a transverse foramen at their base for the vertebral artery (Gray, 1989; Sherk and Parke, 1983).

The axis, C2, is so named for its functional anatomy which provides a pivot, the odontoid process, upon which the atlas rotates. The strong, prominent odontoid process is the most distinctive characteristic of this bone. The body is deeper in front than behind, and projects downward anteriorly overlapping with the anterior portion of C3. The odontoid process possesses two articulating surfaces: (1) a surface situated on the anterior surface for

articulation with the axis which is ovoid in form; and (2) a surface situated on the posterior surface for articulation with the transverse ligament. The internal bone structure of the odontoid process is more compact than that of the body, a functional adaptation necessitated by the stress to which this area is subjected. The pedicles are broad and strong especially in the anterior portion which merges with the sides of the body and the root of the odontoid process. The laminae are thick and robust enclosing the spinal foramen which is large, but smaller than that found in the atlas. The small transverse processes contain the transverse foramen through which the vertebral artery passes. The superior articular surfaces are round, slightly convex, and directed upward and laterally. Their position is distinctive since they are supported on the body, pedicles, and transverse processes. The inferior articular surfaces have the same configuration as those of the "typical" cervical vertebrae. The spinous process is quite large and robust. In the majority of cases, it is bifid in appearance allowing a greater surface area for the attachment of muscles which serve to rotate the head upon the spine (Gray, 1989; Sherk and Parke, 1983).

C7, the "vertebra prominens", has several unique features related to the transitional nature of its position in the spine. The most distinctive feature is its long and prominent spinous process. This process is thick, projects nearly horizontally, and is usually non-bifid. The transverse processes are large, with prominent posterior tubercles, small, weakly defined anterior tubercles and costal

processes that occasionally develop to the size of a vestigial rib. The transverse foramen. are quite variable in their configuration due to the fact that for some unknown reason nothing passes through them. The usual arrangement is for the vertebral artery and vein to pass in front of the transverse process. The foramen are sometimes as large as those found in the other cervical vertebrae, but are usually smaller on one or both sides. In some cases, they are absent alltogether (Gray, 1989; Jackson, 1978, Sherk and Parke, 1983; Taitz et al., 1978).

The skull and vertebrae are linked together by the ligaments and intervertebral discs to provide the neck with a stable yet flexible framework. Cervical vertebrae from the caudal portion of C2 to C7's articulation with the first thoracic vertebrae (T1) are similar in configuration. The ligamentous support between the atlas and axis differs from that of the other vertebrae because of the odontoid process.

There are five ligamentous structures that are special to the area of the atlas and axis: (1) the upward extension of the posterior longitudinal ligament (PLL) known as the tectorial membrane; (2) the alar ligaments; (3) the transverse ligament; (4) the apical ligament; and (5) the accessory atlanto-axial ligaments. The tectorial membrane covers the odontoid process and the following ligaments within the vertebral canal giving them additional strength and reinforcement. The alar ligaments are extremely strong. Originating on either side of the apex of the odontoid process, they pass upward

and laterally to the medial side of the occipital condyles of the skull. These are important check ligaments which limit the rotation of the skull and the atlas on the axis The transverse ligament arises from small tubercles on either side of the anterior arch of the atlas on its posterior surface and from the lateral masses of the atlas. This ligament forms a sling behind the odontoid process to hold it firmly against the midportion of the anterior arch of the atlas. Extending upward from the midportion of the transverse ligament, there is a band which is attached to the margin of the foramen magnum. Extending downward, there is another band which is attached to the midportion of the body of the axis. This gives the transverse ligament the appearance of a cross. These vertical extensions of the transverse ligament add to its strength. The small apical ligament arises from the tip of the odontoid process, extends vertically beneath the superior band of the transverse ligament, and finally anchors securely to the mid-anterior surface of the foramen magnum. The atlanto-axial ligaments are two important check ligaments which extend from the inner aspect of the lateral masses of the atlas downward and slightly inward to become attached to the lateral aspects of the posterior surface of the body of the axis. Their main function is to check excessive rotation of the atlas and the head on the axis (Bailey, 1974; Bateman, 1978; Jackson, 1978; Sherk and Parke, 1983).

The major ligaments of the lower cervical vertebrae include: (1) the anterior longitudinal ligament (ALL); (2) the posterior

longitudinal ligament (PLL); (3) the interspinous ligament; (4) the supraspinous ligament; and (5) the ligamentum flavum. The ALL is unusually broad, beginning at the base of the skull and ending on the anterior surface of the sacrum. It covers the anterior and lateral surfaces of the vertebral bodies and forms their periosteum. The ALL is particularly thick where it is attached to the outer surfaces of the vertebral bodies, and contains only a few elastic fibers. The main function of the ALL is to limit backward bending of the spine. The PLL is narrower than the ALL, but is thicker and contains more elastic fibers. The PLL is firmly attached to the intervertebral discs and spans the slightly concave posterior surfaces of the vertebrae. Unlike the ALL which has a ribbon-like structure, the PLL is waisted over the vertebral bodies and fans out over the intervertebral discs. The main function of the PLL is to limit forward bending of the spine. Therefore, the ALL and PLL act as antagonists in movement of the vertebral column. The interspinous ligament's design lends further support to the other ligaments. It is a somewhat fan-shaped structure which extends from the external occipital protuberance and median nuchal line downward and between the spinous processes of all the cervical vertebrae. The supraspinous ligaments are attached to the tips of the spinous processes. They extend from between two to several vertebrae and merge with the interspinous ligaments to form the nuchal ligament. The nuchal ligament in turn forms a septum at the midline between the muscles of the posterior aspect of the neck. This ligament is much stronger in quadrupeds than in

bipeds because it must help hold the head forward and upward against the force of gravity. Finally, the ligamentum flavum attaches to the anterior surface of the vertebral arch above and to the superior margin of the lamina of the vertebra below. There are two of these ligaments at each level, a right and a left, and they are separated by a small fissure. The ligamentum flavum functions as a stabilizer in flexion because of its high content of elastic tissue (England, 1971; Jackson, 1978; Junghanns, 1971; Sherk and Parke, 1983).

Motion of the head and neck occurs by means of an extremely complex interaction between muscle groups working on the rigid osseous framework supported by the ligamentous system previously described. The muscles located in this region are involved in producing tension, flexion, rotation and lateral bending of the neck and head (Bateman, 1978; Sherk and Parke, 1983; Tortora, 1989). A detailed discussion of these muscle groups is beyond the scope of this paper.

Variation Attributed to Age

Bone is a dynamic tissue that continues to undergo the processes of remodeling throughout the life of an individual (Stout, 1989). Therefore, there are basically two ways to address the topic of age variation in the cervical spine: (1) those which occur during the initial growth stages of the region (i.e. developmental changes); and

(2) those usually occurring, but not limited to, the spine of advanced age (i.e. degenerative changes).

Developmental variation of the cervical spine was discussed in detail previously; therefore, the intrinsic details will not be readdressed. In their study of epiphyseal ring fusion rates of cervical vertebrae, Buikstra and Gordon (1980) collected measurements from a sample of 33 black females from the Terry Collection. They found for their sample that by age 25 all epiphyseal rings were fused to the centra, and that for any given age, vertebrae more cranially located were at a stage of development more advanced than those cervical vertebrae more caudally located. They also addressed the issue of consistent variation patterns within vertebrae either by surface (superior versus inferior) or by aspect of single epiphyses (dorsal versus ventral) for possible use in forensic science study. Vertebrae were graded on a 0-4 scale corresponding to the maturational stage of epiphyseal ring fusion present. No significant maturational differences were found when comparing dorsal and ventral aspects of the same epiphysis, but the surface comparisons indicated that, at least on the ventral aspect, the superior surface of the body was consistently of a more advanced stage than that of the inferior surface. The authors noted that true locational differences in maturational pattern or the effects of age, sex or health status on epiphyseal union may have been reflected in these rates. Roche (1972) used cervical region radiographs to study vertebral elongation in children. The study sample was measured

regularly from 0.25 to 17 years of age. The findings showed that vertebral body height increased rapidly until about 2.5 years of age and then leveled off, except for a growth spurt at about the age of puberty. Discernible sex differences in body height are addressed in the section *Variation Attributed to Sex*.

Degenerative changes in the spine usually associated with advanced age include, but are not limited to, osteophyte development and osteoarthritic lipping (Skogsbergh, 1967). Anthropologists are trained to observe all details of the skeleton. Forensic anthropologists sometimes use degenerative changes manifested in the spine to corroborate advanced age estimations. Stewart (1947) looked at the distribution of osteoarthritic lipping as a possible race discriminator and concluded that the variation seen could possibly be attributed to cultural pattern differences.

According to the research of Jackson (1978), one of the pioneers of extensive cervical spine research, Stewart's (1947) conclusion is rather accurate. Changes that occur at the margins of joints or at the attachment of ligamentous and capsular structures in bone are usually caused by the frequent injuries (i.e. sprains, etc.) sustained in these vulnerable areas. The inflammatory reaction and the disturbance in the mechanico-dynamics of the involved joint or joints causes cartilage cells to form at their periphery. These cartilage cells later ossify and give rise to bony spurs. The changes are then usually termed osteoarthritis, or aging of the joints. She states however, that this condition is the result of trauma, either single or

repeated, and indicative of joint disorder, traumatic in origin. She emphatically denies that the condition is the result of physiologic aging, although they are found to variable degrees in the spines of elderly people and in the spines of bulls, bears, gorillas, horses and other animals.

Jackson (1978) also refers to what she terms "nontraumatic osteoarthritis", which may be the result of biologic, genetic and metabolic factors. These factors may also contribute to traumatic arthritis or to changes in joints subjected to trauma, thus making any sort of differentiation almost impossible.

Therefore, she issues a warning not to gauge the extent or size of an osteophytic formation as an indication of age nor of the severity of the traumatic experience which produced it. It is inevitable that osteophytosis will occur following trauma as long as movement continues, but each individual's response to trauma may vary based on the several aforementioned factors (Jackson, 1978).

Variation Attributed to Race

Vertebrae have been used for racial comparison studies for over 100 years, with most research centering on the discernible differences between whites and blacks. The majority of these studies have focused on measurements of body height, vertebral column length or regional segment length, numerical variation, spinous process morphology and metric analyses. Most of the

discrete variations of the cervical vertebrae, such as doubled and incomplete transverse foramen appear not to be associated with race (Lanier, 1939).

Trotter (1929) investigated possible differences in the vertebral column lengths of whites and blacks. Her measurements and analyses looked at possible differences in the regional segments of the spine, as well as total difference in the length of the columns. Her finding showed that white male columns were longer than black male columns, while black female columns exceeded the white female columns in length. This occurrence was also noted by Lanier (1939). When comparing the regional measurements, it was found that the differences between corresponding segments for the two races were not significant (Trotter, 1929).

Numerical variation in the spine, either addition or subtraction of one vertebra, has been found to be an applicable characteristic to most groups that have been studies. However, within each group the nature of the variation appears to be a characteristic associated more closely with sex than race (Bornstein and Peterson, 1966; De Beer Kaufman 1974, 1977). Therefore, the next section, *Variation Attributed to Sex*, will address this topic in more detail.

In a noted study by Cunningham (1886), the cervical spines of blacks and whites were compared in relation to their morphological appearance. He observed that the spines of blacks were relatively shorter and more stunted in form than those of whites. It was concluded that this condition allowed for greater freedom of

movement in the cervical section of the spine by enabling the vertebrae to collapse upon one another with ease. Shore (1931) took Cunningham's (1886) work and expanded on the observations he had made interjecting an evolutionary slant to morphological variation. Armed with the fact that man is the only anthropoid who possesses bifid spinous processes, he noted that the greater percentage of bifid spinous processes were to be found in whites (European sample), while blacks (Negroids - Bantu and Bushman samples) tended to have a greater number of spines that were non-bifid. He subdivided these observations into more detailed type categories listed under the main classification heading (See Appendix A for a detailed description):

1. Bifid
    a. Bifurcate
    b. Cleft
2. Non-bifid
    a. Acute
    b. Obtuse
    c. Pediculate
    d. Clavate

Based on his classification system, he found that the bifid characteristic occurred in about 71% of the European sample and only 7% of the Bushmen sample. Of the Bantu sample, 21% had bifid spines placing them in-between the European and Bushmen sample,

but closer to that of the Bushmen. Non-bifid spinous processes dominated the Bantu and Bushmen findings, with all 4 categories represented in the sample. Delving into the evolutionary aspect, Shore hypothesized that the bifid quality of the cervical spinous processes in Europeans is a recessive (retrogressive) condition. He cites the fact that non-bifid spinous processes occurred sporadically in the five lower cervical vertebrae (C3-C7, with C7 expressing the clavate trait almost 100% of the time) of Europeans in his sample. With C7, Shore felt this bifid to non-bifid change had attained almost virtual completeness in the European sample. The C6 vertebrae had the second highest percentage of non-bifidity in his sample of Europeans; therefore, he concluded that this change is moving cranially. Allbrook (1955) and Lanier (1939) point out that there is no solid evidence for Shore's hypothesis. Allbrook (1955) states that the morphological differences viewed in the cervical spine may be due to something as simple as a small variation in the muscle attachment configuration. With all conflicting hypotheses aside one significant hypothesis remains: bifid cervical spinous processes occur more frequently in whites than in blacks.

Metric analyses with statistical correlations have also been employed by researchers in an effort to possibly discern racial differences. Lanier (1939) collected 10 different measurements on the presacral vertebrae of 101 white males and 100 black males. Only in the cervical region of the spine did vertebrae measurements of blacks exceed those of whites. The cervical body for black males

was deeper from anterior to posterior than in the white males, and the transverse diameters of the vertebral foramen of C4-C7 were considerably larger for the black males. Others (Allbrook, 1955; Shore, 1931) have observed that the transverse foramen of blacks tend to be more rounded in shape compared to the oval shape of the transverse foramen in whites which would account for this difference in transverse diameter. Several measurements between black and white males were found to have statistical significance including: (1) the maximum transverse diameter of the atlas was found to be greater in whites; (2) the anterior vertical diameter of the centra was found to be greater in white males - this is an accumulative difference that leads to a longer spinal column in white males versus black males; (3) the mid-vertical diameter of the centrum was found to be greater in white males - an accumulative difference that produces a longer spinal column in white males; (4) the angle of inclination of the cervical spinous process tends to be more horizontal in the black male; and (5) the lumbar spinous process tends to be more horizontal in white males (Lanier, 1939).

Variation Attributed to Sex

Past research has paid little attention to vertebral differences between the sexes. This may have been due to the lack of documented female skeletal materials available to researchers during the predominant time of intensive spinal research.

The most obvious difference is in the size of the vertebrae; female vertebrae, on the average, are proportionally smaller than those of males (Thieme and Schull, 1957; Tortora, 1989). When comparing segment lengths, Trotter (1929) found that the male columns were longer than the female columns, but that the female columns showed less variation than the males. She also noted that the female columns, in both blacks and whites, showed a general tendency for less curvature versus the male columns.

In a longitudinal study of cervical vertebrae body height growth, Roche (1972) regularly examined the radiographs of 32 children from the age of 0.25 years until the age of 17. Between the ages of 0.25 and 12 years there was little discernible differences between the sexes, but from the age of 12-15, the female vertebral body heights exceeded those of the males. This sex difference was reversed after the age of 15 in favor of the males who surpassed the body heights of the females in the sample. In a similar study by Bench (1963), he found a notable sex difference between the ages of 12-18 with the body heights of females in his sample growing at a rate per year only one-third to that of the males. Therefore, the variation was attributed to the greater vertebral body elongation seen in males versus females; this would be expected in light of the findings of Trotter (1929).

Numerical variation, either through addition or subtraction of vertebrae, has been found to be sexually correlated in all populations studied thus far, including American whites, American blacks,

Mongoloids, South African blacks, and Bushman (San) (Bornstein and Peterson, 1966; DeBeer Kaufman, 1974, 1977). The overall incidence of variation between samples studied ranged from between 11% and 30%. Males were found to have a higher frequency of 25 presacral vertebrae (PSV), while females possessed a higher frequency of 23 PSVs. All data strongly suggest that the total frequency variation in the number of presacral vertebrae is a specific characteristic of any particular population group, and that in all population groups studied, the tendency was toward an increase in the number of PSVs in males and a decrease in number in females (Bornstein and Peterson, 1966; DeBeer Kaufman, 1974, 1977).

CHAPTER 2

RESEARCH OBJECTIVES

The primary objectives of this research are:

1. To estimate the strength of the relationship between cervical spinous process (C2-C7) gross morphological type categorization and race.

2. To discriminate groups, race and/or sex, using metric variation.

The null hypothesis for this research is that gross morphological and/or metric variation are not correlated with race and/or sex in the cervical spine (C2-C7). The test hypothesis is that gross morphological and/or metric variation of the cervical spine (C2-C7) are correlated with race and/or sex differences.

CHAPTER 3

MATERIALS AND METHODS

William M. Bass Collection Sample

A total of 86 individuals from the William M. Bass Collection, housed at the Department of Anthropology, University of Tennessee-Knoxville, were included in the total data sample (Table 1). This collection consists of modern, donated skeletal materials of known race and sex collected by Dr. William M. Bass. Collection efforts are ongoing; hence, the collection continues to grow and diversify.

The second (C2) through seventh (C7) cervical vertebrae were measured. Race and sex were known at the time of data collection. In cases of missing, broken or fused vertebrae, only those available and/or complete enough for all or a portion of the measurements were included in the data sample. C1 was omitted from the data sample because its specialized shape and function precluded the measurements necessary for inclusion in this study. The variability in sample size between groups is a reflection of the total composition of the collection at the time of sampling.

TABLE 1: Composition of the Bass Collection sample (N=86).

Race	Sex	N
White	Male	48
White	Female	12
Black	Male	18
Black	Female	8
	Total:	86

Terry Anatomical Collection Sample

A total of 88 individuals from the Terry Collection, housed at the Smithsonian Institution in Washington, D. C., were included in the total data sample (Table 2). The Terry Collection is composed of the skeletal remains of 1636 cadavers which were collected and macerated during the early to mid-twentieth century in St. Louis, Missouri. The Negroid skeletons in the collection are descendants of original slaves, and display characteristics ranging from Negroid to varying degrees of Caucasoid-Negroid and, possibly, Amerindian (Mongoloid) intermixture. The Caucasoid skeletons are from native born and foreign parentage, and are believed to be representative of Mid-West dissecting-room materials of that time period (Lanier, 1939; Terry, 1940).

The same inclusion criteria utilized for the Bass Collection were applied to the Terry Collection. These individuals were randomly chosen based on race and sex. In an effort to standardize the group sizes and compensate for the over-sampling of white males in the Bass sample, they were omitted from collection in the Terry sample.

Data Collection

Spinous process type was recorded and measurements, in millimeters, were taken on the sampled skeletal materials from both

TABLE 2: Composition of the Terry Collection sample (N=88).

Race	Sex	N
White	Male	0
White	Female	28
Black	Male	29
Black	Female	31
	Total:	88

collections (Appendix A). Race and sex were known and recorded at the time of data collection in order to define the groups. Type categorization strictly adhered to the definitions set forth by Shore (1931) (see Appendix B for type definitions). By following these standardized definitions, it was hoped that intraobserver error in the categorization of these types would minimized (DeStefano et al., 1984). With the exception of C2, the five measurements used to discriminate groups, race and/or sex, include: (1) minimum width of spinous process; (2) maximum width of spinous process; (3) maximum length of spinous process; (4) angle of spinal inclination; and (5) body (centrum) height (See Appendix C for measurement definitions). The angle of spinal inclination measurement is unavailable for C2 because its unique anatomical configuration prevents the proper measurement technique.

A random ten percent sample from each collection was remeasured as a check for intraobserver error. The measurement differences found in both samples were low and the error rate did not exceed ± 0.4 millimeters. Nominal classification error was also low, with 4 idividuals misclassified (2 black males/2 white females).

All measurements, except for the angle of spinal inclination, were taken with a Craftsman vernier caliper and recorded to the nearest tenth of a millimeter. The angle of spinal inclination was recorded to the nearest degree utilizing a modified protractor with a straight edge. modeled after Lanier (1939). These data were recorded on specially designed data forms (See Appendix D).

Statistical Methods

All data were entered for statistical analyses using the JMP system (JMP User's Guide, 1989). The first step was to compare the two collections to discern any significant differences which would prevent pooling of the collections. The nominal data were compared utilizing Chi^2 and the interval data were compared utilizing t-tests (Tables 3 and 4). Since a large number of univariate tests were run, the alpha level of 0.05 was divided by the number of tests run, 35, which yielded 0.0014286 or 0.001. Accordingly, 0.001 was the probability required to reject at 0.05. No significant differences were found between the collections; therefore, the data were pooled. In sum, the total data sample of 174 individuals was composed of the following: (1) 48 white males, (2) 47 black males, (3) 40 white females and (4) 39 black females.

The statistical tests applied to the interval variables for this total data sample include canonical discriminant analysis, the MANOVA, and discriminant analysis. The canonical discriminant analyses allowed for a comparison of the 4 groups (WM, BM, WF, and BF) in relation to the measurement variables. The MANOVA procedure allows for a comparison of inter- and intra-group variation. In this study, the procedure tested for significance by race, by sex, and by race*sex. Discriminant analysis is a method of predicting some level

TABLE 3: Collection comparison Chi^2 probabilities for type of spinous process classification by groups.

Variable	S.P.	BF	BM	WF
Type of S.P.	C2	0.7807	0.6456	0.0173
	C3	0.7300	0.0592	0.0356
	C4	0.0121	0.4243	0.5020
	C5	0.0101	0.9408	0.5468
	C6	0.6507	0.2756	0.2879
	C7	0.2508	0	0

TABLE 4: Collection comparison t-test probabilities for interval data by groups.

Variable	S.P.	BF	BM	WF
Min. Width of S.P.	C2	0.8453	0.0206	0.7934
	C3	0.7407	0.2563	0.0611
	C4	0.2215	0.9947	0.1117
	C5	0.4914	0.2210	0.0047
	C6	0.4304	0.0420	0.0731
	C7	0.2509	0.2239	0.1959
Max. Width of S.P.	C2	0.3054	0.1503	0.7150
	C3	0.1351	0.9743	0.2644
	C4	0.2186	0.6994	0.1324
	C5	0.6950	0.8755	0.0369
	C6	0.0152	0.4631	0.8056
	C7	0.5584	0.7132	0.4865
Max. Length of S.P.	C2	0.7961	0.5788	0.1613
	C3	0.7436	0.0274	0.9296
	C4	0.5890	0.1628	0.8063
	C5	0.7800	0.6373	0.8833
	C6	0.7686	0.7221	0.1241
	C7	0.2032	0.2087	0.0857
Angle of S.P.	C3	0.0500	0.0034	0.1560
	C4	0.2239	0.0084	0.8401
	C5	0.1027	0.0310	0.9958
	C6	0.0962	0.6106	0.4343
	C7	0.0681	0.0177	0.7965
Centrum Ht.	C2	0.8898	0.0562	0.0680
	C3	0.4885	0.7760	0.1276
	C4	0.7917	0.2368	0.2535
	C5	0.9846	0.4450	0.9404
	C6	0.9737	0.1840	0.2114
	C7	0.9753	0.3784	0.5099

of a one-way classification based on known values of the responses. This technique classifies based on how close a set of measurement variables are to the multivariate means of the levels being predicted (Tatsuoka, 1970). In this case, classification was attempted based on race, sex and group for possible use in the forensic setting.

Response profiles and graphic representations were utilized in an attempt to classify spinous process type categorization data and race. The type categorization data was then collapsed under the main category headings, bifid and non-bifid, in an attempt to gain a better overall picture of the variation. In addition to the response profiles and graphic representations, Chi^2 probabilities were also calculated for bifid/non-bifid type classifications in order to compare with other researcher's work in this area (Allbrook, 1955; Cunningham, 1886; Lanier, 1939; Shore, 1931).

CHAPTER 4

RESULTS

The interval data from this study were subjected to a series of multivariate statistical analyses to determine whether a significant difference exists between groups, race and/or sex, and, if it does, could it be discriminated. Response profiles and Chi^2 probabilities were also generated to estimate the strength of the relationship between spinous process gross morphological types and race.

It has been hypothesized that gross morphological and/or metric variation of the cervical spine are correlated with race and/or sex differences. The results of this study show that differences do exist in the dimensions of the vertebrae and in spinous process gross morphology. These differences could be discriminated with a 69%-80% accuracy rate for race and a 69%-85% accuracy rate for sex. Discriminating by group was found to be generally unreliable with accuracy rates ranging from 43%-82% for black females, 25%-55% for black males, 38%-61% for white females, and 66%-81% for white males. Chi^2 probabilities calculated for the type of spinous process by race were found to be significant for C3, C4, and C5, which corresponds with observations made by Allbrook (1955), Cunningham (1886), Lanier, (1939), and Shore (1931).

Canonical discriminant analysis was utilized as a means of comparing the 4 groups in relation to the measurement variables

(Blackith and Reyment, 1971). The centroids (multivariate least-squares means) of each group were plotted on the first two canonical variables formed from the test space (Figs. 1-6). The centroid points appear with circles corresponding to the 95% confidence regions. The means are well separated (discriminated) for C2-C7, with white males and black females showing the greatest distance apart.

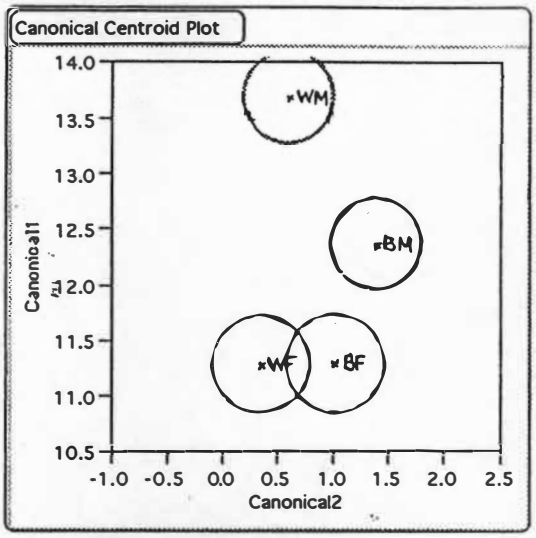
Correlation coefficients were calculated in order to discern which response variables contributed the most to canonical[1] and canonical[2] respectively (Table 5). Centrum height was highly correlated with canonical[1] for all vertebrae (C2-C7). The variables correlated with canonical [2] were dependent on the vertebra studied. They included: (1) minimum width of the spinous process for C2-C5; (2) maximum width of the spinous process for C6; and (3) angle of the spinous process for C7. Therefore, the greatest variability between the means of these groups is centrum height. The next greatest variability (as demonstrated in canonical[2]) is not as clearly indicated with differences occurring based on the vertebrae sampled.

It is apparent from the plots that canonical[1] represents nearly all the variation in size, with white males and black females displayed on the high and low ends of the spectrum respectively. Black males and white females are usually represented between these two extremes and generally are plotted in close proximity to

GROUP

Test	Value	Approx. F	DF Num	DF Den	Prob>F
Wilks' Lambda	0.4291496	12.8019	12	407.74	0.0000
Pillai's Trace	0.642656	10.6321	12	468	0.0000
Hotelling-Lawley	1.1630375	14.7964	12	458	0.0000
Roy's Max Root	0.9954629	38.8231	4	156	0.0000

CentroidVal



EigenValue	Canonical Corr
0.99546289	0.70630245
0.16655824	0.37785907
0.00101638	0.0318645
1.04e-19	3.22e-10

Eigvec

MIN. WIDTH OF S.P.	-0.0120842	0.01244882	0.01642681	0.0241879
MAX. WIDTH OF S.P.	0.02187934	0.00176776	0.00051967	-0.0315742
MAX. LENGTH OF S.P.	0.01363303	0.02650411	-0.0199937	0.00912834
CENTRUM HT.	0.02275115	-0.023571	0.00977653	0.01633774

RACE

Test	Value	Exact F	DF Num	DF Den	Prob>F
F Test	0.2440356	9.3954	4	154	0.0000

SEX

Test	Value	Exact F	DF Num	DF Den	Prob>F
F Test	0.7964544	30.6635	4	154	0.0000

RACE*SEX

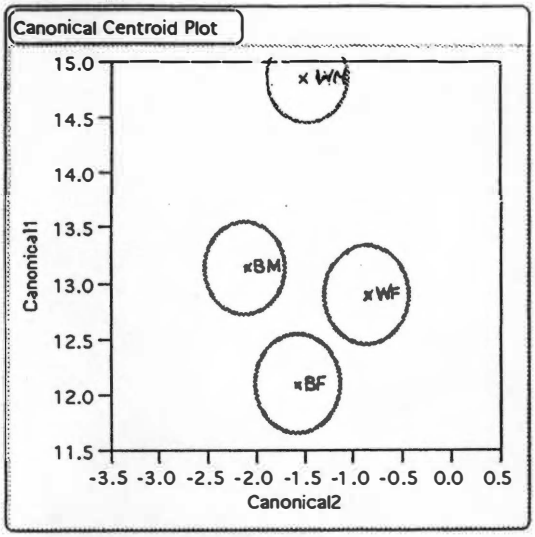
Test	Value	Exact F	DF Num	DF Den	Prob>F
F Test	0.1152341	4.4365	4	154	0.0020

FIG. 1: C2 centroid plots for canonical[1] and canonical[2] with significance test results for race, sex, and race*sex.

GROUP

Test	Value	Approx. F	DF Num	DF Den	Prob>F
Wilks' Lambda	0.4011344	10.8378	15	414.49	0.0000
Pillai's Trace	0.6899722	9.0800	15	456	0.0000
Hotelling-Lawley	1.2675762	12.5631	15	446	0.0000
Roy's Max Root	1.0577868	32.1567	5	152	0.0000

CentroidVal



EigenValue	Canonical Corr
1.05778678	0.71696653
0.20149021	0.40951221
0.00829922	0.09072435
4.24e-22	2.06e-11
-1.12e-20	0

Eigvec

MIN. WIDTH OF S.P.	0.00370604	0.01653876	0.0263546	0.00812781	-0.0327486
MAX. WIDTH OF S.P.	0.00597893	0.0086827	-0.0182305	-0.0174653	0.02559565
MAX. LENGTH OF S.P.	0.00797504	-0.0042881	0.02618871	0.00207139	0.01062225
ANGLE OF S.P.	0.00097515	0.00311424	-0.000578	0.00923578	0.00514464
CENTRUM HT.	0.06022688	-0.0255725	-0.0119884	0	-0.0237506

RACE

Test	Value	Exact F	DF Num	DF Den	Prob>F
F Test	0.5224408	15.6732	5	150	0.0000

SEX

Test	Value	Exact F	DF Num	DF Den	Prob>F
F Test	0.6618238	19.8547	5	150	0.0000

RACE*SEX

Test	Value	Exact F	DF Num	DF Den	Prob>F
F Test	0.0629622	1.8889	5	150	0.0995

FIG. 2: C3 centroid plots for canonical[1] and canonical[2] with significance test results for race, sex, and race*sex.

GROUP

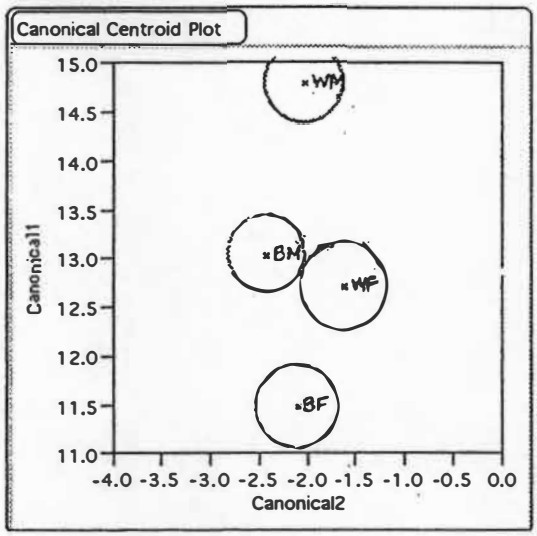
Test	Value	Approx. F	DF Num	DF Den	Prob>F
Wilks' Lambda	0.3759253	12.2227	15	431.05	0.0000
Pillai's Trace	0.6719707	9.1211	15	474	0.0000
Hotelling-Lawley	1.5333888	15.8109	15	464	0.0000
Roy's Max Root	1.4466062	45.7128	5	158	0.0000

EigenValue	Canonical Corr
1.44660619	0.76894119
0.08084796	0.27349679
0.00593464	0.07680903
4.28e-20	2.07e-10
2.88e-20	1.7e-10

Eigvec

MIN. WIDTH OF S.P.	-0.0038157	0.02285275	0.01527904	-0.0411385	0.00551037
MAX. WIDTH OF S.P.	0.0140539	0.00261379	-0.0040036	0.03615345	-0.0134679
MAX. LENGTH OF S.P.	0.00043423	-0.0019492	0.01963695	0.0073839	0.01378299
ANGLE OF S.P.	-0.0009345	0.00285425	-0.0046582	0.00367404	0.00923692
CENTRUM HT.	0.06912406	-0.0320692	-0.0130316	-0.0259955	0

CentroidVal



RACE

Test	Value	Exact F	DF Num	DF Den	Prob>F
F Test	0.6110157	19.0637	5	156	0.0000

SEX

Test	Value	Exact F	DF Num	DF Den	Prob>F
F Test	0.8803327	27.4664	5	156	0.0000

RACE*SEX

Test	Value	Exact F	DF Num	DF Den	Prob>F
F Test	0.0247931	0.7735	5	156	0.5702

FIG. 3: C4 centroid plots for canonical[1] and canonical[2] with significance test results for race, sex, and race*sex.

GROUP

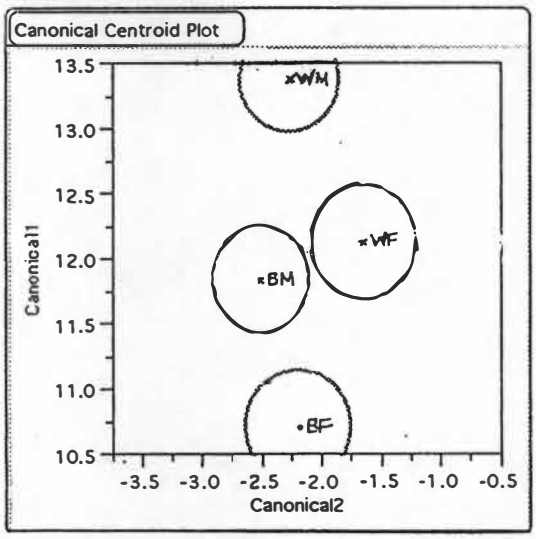
Test	Value	Approx. F	DF Num	DF Den	Prob>F
Wilks' Lambda	0.4658089	9.1622	15	431.05	0.0000
Pillai's Trace	0.5826627	7.6167	15	474	0.0000
Hotelling-Lawley	1.0436907	10.7616	15	464	0.0000
Roy's Max Root	0.9355713	29.5641	5	158	0.0000

EigenValue	Canonical Corr
0.93557134	0.69523858
0.09776776	0.29843008
0.01035159	0.10122024
1.52e-20	1.23e-10
-2.01e-20	0

Eigvec

MIN. WIDTH OF S.P.	0.00040798	0.01829879	-0.0052581	0.03794777	-0.0265762
MAX. WIDTH OF S.P.	0.01509827	0.00582702	-0.0006296	-0.0137286	0.03364308
MAX. LENGTH OF S.P.	0.00211002	-0.0015146	0.01815855	0.01039089	0.00396682
ANGLE OF S.P.	0.00154458	0.00380465	0.00624158	-0.0062333	-0.0033625
CENTRUM HT.	0.05248744	-0.0344906	-0.0133775	-0	-0.0237539

CentroidVal



RACE

Test	Value	Exact F	DF Num	DF Den	Prob>F
F Test	0.5942051	18.5392	5	156	0.0000

SEX

Test	Value	Exact F	DF Num	DF Den	Prob>F
F Test	0.4187837	13.0661	5	156	0.0000

RACE*SEX

Test	Value	Exact F	DF Num	DF Den	Prob>F
F Test	0.0164932	0.5146	5	156	0.7650

FIG. 4: C5 centroid plots for canonical[1] and canonical[2] with significance test results for race, sex, and race*sex.

GROUP

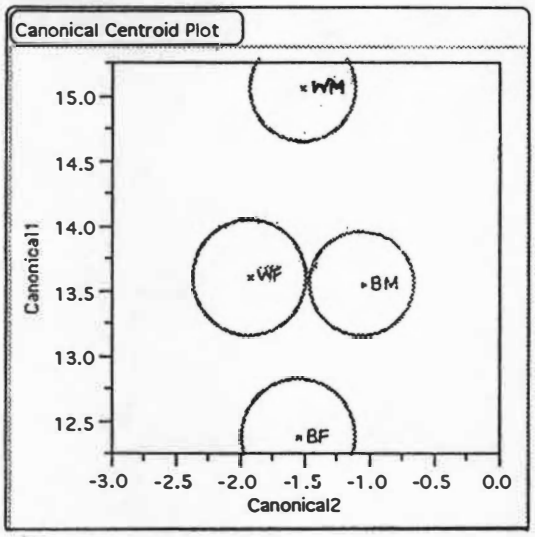
Test	Value	Approx. F	DF Num	DF Den	Prob>F
Wilks' Lambda	0.4457236	9.7722	15	431.05	0.0000
Pillai's Trace	0.6271239	8.3515	15	474	0.0000
Hotelling-Lawley	1.0855217	11.1929	15	464	0.0000
Roy's Max Root	0.9272401	29.3008	5	158	0.0000

EigenValue	Canonical Corr
0.92724012	0.69363052
0.09970153	0.3011019
0.05858	0.23524091
8.59e-21	9.27e-11
6.78e-21	8.23e-11

Eigvec

MIN. WIDTH OF S.P.	-0.0002178	-0.033918	0.0621563	0.01111961	-0.0113945
MAX. WIDTH OF S.P.	0.01416268	0.02295	-0.0259415	0.02026419	-0.019417
MAX. LENGTH OF S.P.	0.00082934	0.00366606	0.00212816	0.00806379	0.01396772
ANGLE OF S.P.	0.00290377	-0.0061676	-0.0058947	0.00467086	0.00611935
CENTRUM HT.	0.06246803	-0.0040346	0.00267896	-0.0424443	0

CentroidVal



RACE

Test	Value	Exact F	DF Num	DF Den	Prob>F
F Test	0.5198569	16.2195	5	156	0.0000

SEX

Test	Value	Exact F	DF Num	DF Den	Prob>F
F Test	0.4907071	15.3101	5	156	0.0000

RACE*SEX

Test	Value	Exact F	DF Num	DF Den	Prob>F
F Test	0.0634701	1.9803	5	156	0.0845

FIG. 5: C6 centroid plots for canonical[1] and canonical[2] with significance test results for race, sex, and race*sex.

GROUP

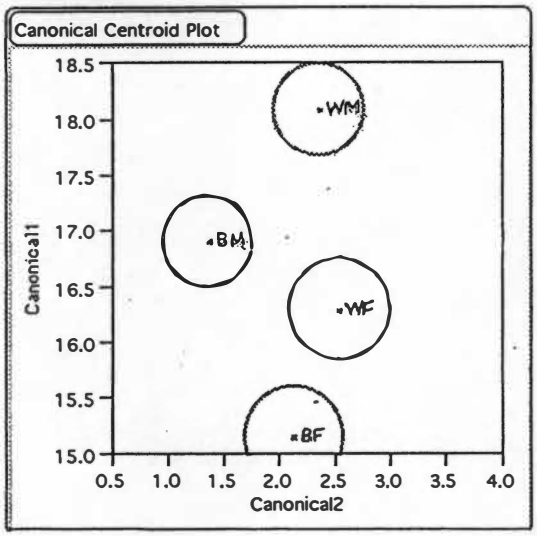
Test	Value	Approx. F	DF Num	DF Den	Prob>F
Wilks' Lambda	0.3721458	12.1352	15	422.77	0.0000
Pillai's Trace	0.7430256	10.2056	15	465	0.0000
Hotelling-Lawley	1.3862024	14.0160	15	455	0.0000
Roy's Max Root	1.1353412	35.1956	5	155	0.0000

EigenValue	Canonical Corr
1.13534122	0.72917129
0.21593621	0.42141243
0.03492495	0.18370182
1.85e-20	1.36e-10
-6.98e-20	0

Eigvec

MIN. WIDTH OF S.P.	0.01873768	-0.0149889	-0.0473239	0.05460679	0.00372621
MAX. WIDTH OF S.P.	0.00420556	-0.0096423	0.042511	0.00098581	0.01569163
MAX. LENGTH OF S.P.	0.00996047	-0.0075574	-0.0060377	-0.012084	0.01104891
ANGLE OF S.P.	0.00202871	0.00936872	-0.0009141	0.00336146	0.00781966
CENTRUM HT.	0.05427155	0.02277926	0.00438945	-0	-0.0536712

CentroidVal



RACE

Test	Value	Exact F	DF Num	DF Den	Prob>F
F Test	0.4681568	14.3256	5	153	0.0000

SEX

Test	Value	Exact F	DF Num	DF Den	Prob>F
F Test	0.8547922	26.1566	5	153	0.0000

RACE*SEX

Test	Value	Exact F	DF Num	DF Den	Prob>F
F Test	0.0529706	1.6209	5	153	0.1577

FIG. 6: C7 centroid plots for canonical[1] and canonical[2] with significance test results for race, sex, and race*sex.

TABLE 5: Correlation coefficients of each variable with canon[1] and canon[2] by vertebra.

	Variable	Canon[1]	Canon[2]
C2	Min. width of s.p.	0.1482	0.5575
	Max. width of s.p.	0.5784	0.4011
	Max. length of s.p.	0.6345	0.4912
	Centrum ht.	0.8322	-0.3744
C3	Min. width of s.p.	0.3669	0.8595
	Max. width of s.p.	0.5142	0.7256
	Max. length of s.p.	0.3255	-0.2783
	Angle of s.p.	0.3083	0.3824
	Centrum ht.	0.9408	-0.2305
C4	Min. width of s.p.	0.5142	0.8179
	Max. width of s.p.	0.6577	0.6426
	Max. length of s.p.	0.1938	-0.2512
	Angle of s.p.	0.2215	0.4270
	Centrum ht.	0.9483	-0.2043
C5	Min. width of s.p.	0.4992	0.7360
	Max. width of s.p.	0.6992	0.5320
	Max. length of s.p.	0.0864	-0.3800
	Angle of s.p.	0.3688	0.5589
	Centrum ht.	0.8948	-0.3808
C6	Min. width of s.p.	0.4352	-0.3220
	Max. width of s.p.	0.5988	0.2797
	Max. length of s.p.	0.2861	0.5813
	Angle of s.p.	0.2207	-0.8057
	Centrum ht.	0.9352	0.0767
C7	Min. width of s.p.	0.4493	-0.4804
	Max. width of s.p.	0.4702	-0.3668
	Max. length of s.p.	0.7145	-0.2916
	Angle of s.p.	0.2293	0.8401
	Centrum ht.	0.8926	0.2195

one another on the vertical axis of canonical[1]. The variation presented in canonical[2] orders the data in three different ways. First, C2-C5 finds minimum width of the spinous process to be significantly correlated with canonical[2]. This variability may be a reflection of the fact that these vertebrae exhibited the greatest amount of spinous process type diversity in the sample. Second, maximum length of the spinous process is correlated with canonical[2] in C6. The fact that the spinal type of this vertebra varies between a propensity toward the long, clavate type and most other defined shorter types, may contribute to this high variability. Third, the angle of the spinous process is correlated with canonical[2] in C7. C7 is considered a transitional vertebra, possessing characteristics of both the cervical and thoracic regions, which may be a factor in its angular variability.

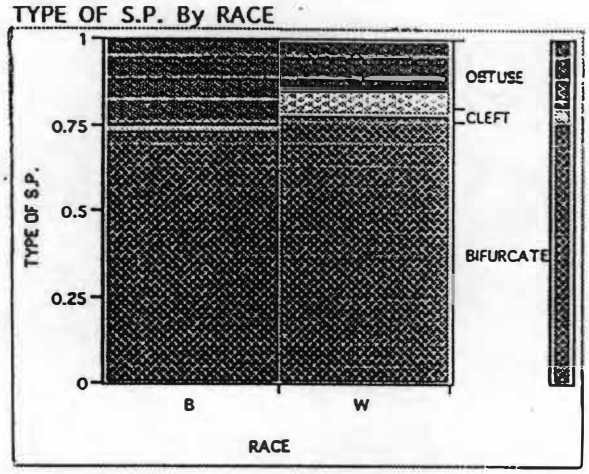
In addition to the canonical analyses, the MANOVA was utilized to test for significance by race, by sex and by the race*sex interaction for each vertebra (Figs. 1-6). Significance was assessed at the $p=0.05$ level. All vertebrae tested highly significant for race and sex ($p=<0.0001$). The interaction of race*sex was only significant for C2 ($p=0.0020$). The next closest values were those for C3 ($p=0.0995$) and C6 ($p=0.0845$); however, they are not significant at the level determined for this study. The other p-values, which are all insignificant, range from 0.1577 to 0.7650.

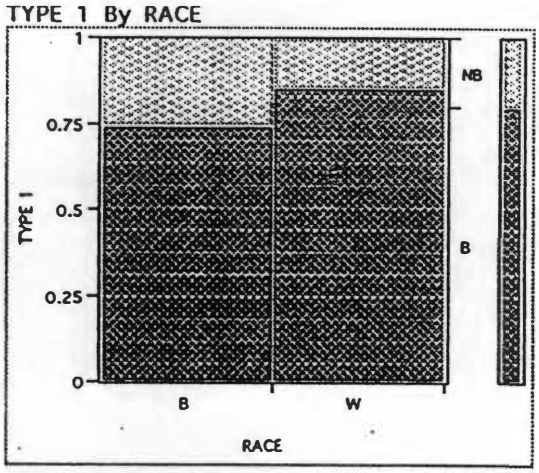
In order to estimate the strength of the relationship between spinous process types (Shore, 1931) for this sample and race,

response profiles with graphical representations were generated for C2-C6 (Figs. 7-12). C7 was omitted from categorical analysis since only two individuals deviated from the clavate type. Overall, the black individuals sampled had a higher incidence of the non-bifid spine types (acute, obtuse, pediculate, and clavate) and the white individuals sampled had a higher incidence of the bifid spine types (bifurcate and cleft). All spinous process types were observed in the sample for both race groups, so it should not be assumed that they are particular to a specific group.

The type categorization data was then collapsed under the main category headings, bifid and non-bifid, to formulate a clearer overall picture of variation. In addition to response profiles, Chi^2 probabilities were also calculated (Figs. 7-12). Assessing significance at the $p=0.05$ level, C3 (< 0.0001), C4 (0.0003), and C5 (0.0108) were found to be significant for type of spinous process (bifid or non-bifid) by race. The other p-values, which were are all insignificant, ranged from 0.0851 to 0.6984.

Discriminant analysis was employed for measurements recorded to determine if classifications could be predicted based on race, sex and group (Tatsuoka, 1970). Cross-validation was included in the JMP program for discriminant analysis. Race classification was found to be significant for C2-C7 (Table 6). Blacks were correctly classified 72%-80% of the time depending on which vertebra was utilized. For whites, a 69%-75% classification rate was achieved.





Summary of Fit

Analysis of LogLikelihood

Response Counts

TYPE OF S.P.	B	W	Total
BIFURCATE	61	64	125
CLEFT	1	6	7
OBTUSE	21	12	33
	83	82	165

Response Profiles

TYPE OF S.P.	B	W	All
BIFURCATE	0.7349	0.7805	0.7576
CLEFT	0.0120	0.0732	0.0424
OBTUSE	0.2530	0.1463	0.2000
	83	82	165

Summary of Fit

Analysis of LogLikelihood

Source	DF	-LogLikelihood
Model	1	1.482501
Error	163	81.083899
C Total	164	82.566400

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	2.965	0.0851
Pearson	2.933	0.0868

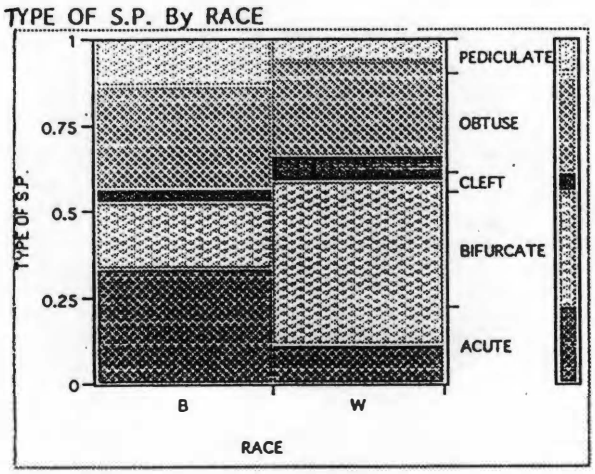
Response Counts

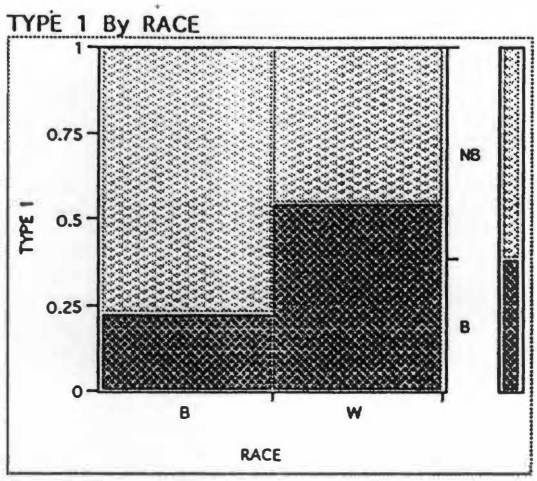
TYPE 1	B	W	Total
B	62	70	132
NB	21	12	33
	83	82	165

Response Profiles

TYPE 1	B	W	All
B	0.7470	0.8537	0.8000
NB	0.2530	0.1463	0.2000
	83	82	165

FIG. 7: C2 response profiles with graphical representation for type of spinous process and bifid/non-bifid classification by race.





Summary of Fit

Analysis of LogLikelihood

Response Counts

TYPE OF S.P.	B	W	Total
ACUTE	28	9	37
BIFURCATE	16	38	54
CLEFT	3	6	9
OBTUSE	25	22	47
PEDICULATE	11	5	16
	83	80	163

Response Profiles

TYPE OF S.P.	B	W	All
ACUTE	0.3373	0.1125	0.2270
BIFURCATE	0.1928	0.4750	0.3313
CLEFT	0.0361	0.0750	0.0552
OBTUSE	0.3012	0.2750	0.2883
PEDICULATE	0.1325	0.0625	0.0982
	83	80	163

Summary of Fit

Analysis of LogLikelihood

Source	DF	-LogLikelihood
Model	1	9.04476
Error	161	99.70202
C Total	162	108.74678

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	18.090	0.0000
Pearson	17.711	0.0000

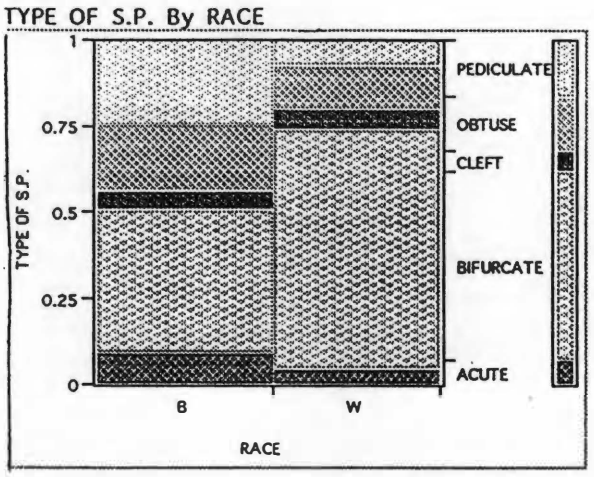
Response Counts

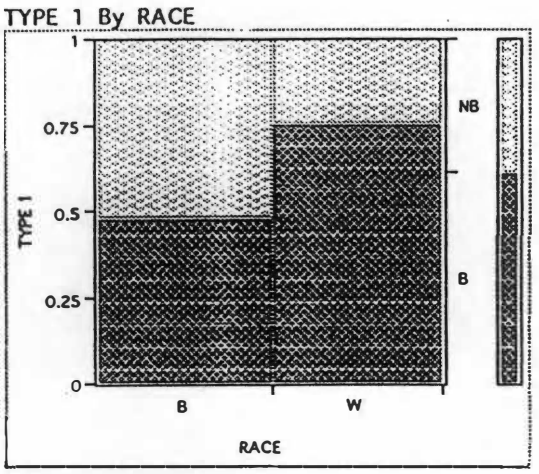
TYPE 1	B	W	Total
B	19	44	63
NB	64	36	100
	83	80	163

Response Profiles

TYPE 1	B	W	All
B	0.2289	0.5500	0.3865
NB	0.7711	0.4500	0.6135
	83	80	163

FIG. 8: C3 response profiles with graphical representation for type of spinous process and bifid/non-bifid classification by race.





Summary of Fit

Analysis of LogLikelihood

Response Counts

TYPE OF S.P.	B	W	Total
ACUTE	8	4	12
BIFURCATE	35	56	91
CLEFT	5	5	10
OBTUSE	16	10	26
PEDICULATE	21	6	27
	85	81	166

Response Profiles

TYPE OF S.P.	B	W	All
ACUTE	0.0941	0.0494	0.0723
BIFURCATE	0.4118	0.6914	0.5482
CLEFT	0.0588	0.0617	0.0602
OBTUSE	0.1882	0.1235	0.1566
PEDICULATE	0.2471	0.0741	0.1627
	85	81	166

Summary of Fit

Analysis of LogLikelihood

Source	DF	-LogLikelihood
Model	1	6.53724
Error	164	104.13699
C Total	165	110.67423

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	13.074	0.0003
Pearson	12.833	0.0003

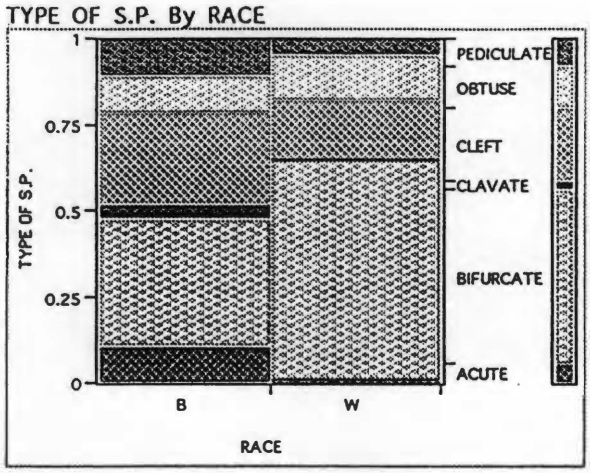
Response Counts

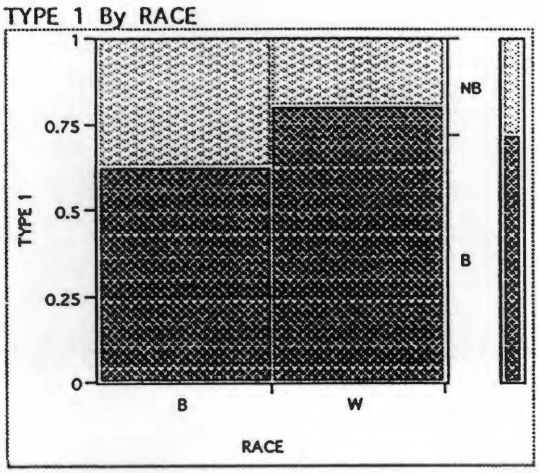
TYPE 1	B	W	Total
B	41	61	102
NB	44	20	64
	85	81	166

Response Profiles

TYPE 1	B	W	All
B	0.4824	0.7531	0.6145
NB	0.5176	0.2469	0.3855
	85	81	166

FIG. 9: C4 response profiles with graphical representation for type of spinous process and bifid/non-bifid classification by race.





Summary of Fit

Analysis of LogLikelihood

Response Counts

TYPE OF S.P.	B	W	Total
ACUTE	9	1	10
BIFURCATE	31	53	84
CLAVATE	4	0	4
CLEFT	22	14	36
OBTUSE	9	11	20
PEDICULATE	9	4	13
	84	83	167

Response Profiles

TYPE OF S.P.	B	W	All
ACUTE	0.1071	0.0120	0.0599
BIFURCATE	0.3690	0.6386	0.5030
CLAVATE	0.0476	0.0000	0.0240
CLEFT	0.2619	0.1687	0.2156
OBTUSE	0.1071	0.1325	0.1198
PEDICULATE	0.1071	0.0482	0.0778
	84	83	167

Summary of Fit

Analysis of LogLikelihood

Source	DF	-LogLikelihood
Model	1	3.251539
Error	165	95.997482
C Total	166	99.249020

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	6.503	0.0108
Pearson	6.415	0.0113

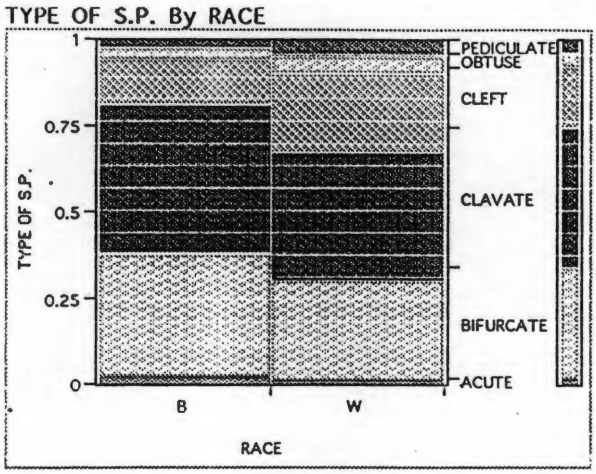
Response Counts

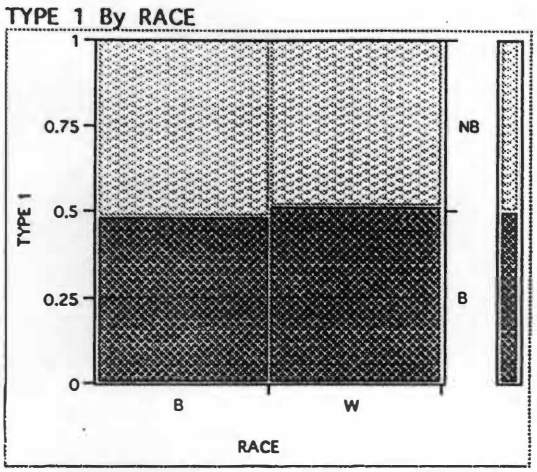
TYPE 1	B	W	Total
B	53	67	120
NB	31	16	47
	84	83	167

Response Profiles

TYPE 1	B	W	All
B	0.6310	0.8072	0.7186
NB	0.3690	0.1928	0.2814
	84	83	167

FIG. 10: C5 response profiles with graphical representation for type of spinous process and bifid/non-bifid classification by race.





Summary of Fit

Analysis of LogLikelihood

Response Counts

TYPE OF S.P.	B	W	Total
ACUTE	2	1	3
BIFURCATE	30	24	54
CLAVATE	36	31	67
CLEFT	11	19	30
OBTUSE	3	4	7
PEDICULATE	2	4	6
	84	83	167

Response Profiles

TYPE OF S.P.	B	W	All
ACUTE	0.0238	0.0120	0.0180
BIFURCATE	0.3571	0.2892	0.3234
CLAVATE	0.4286	0.3735	0.4012
CLEFT	0.1310	0.2289	0.1796
OBTUSE	0.0357	0.0482	0.0419
PEDICULATE	0.0238	0.0482	0.0359
	84	83	167

Summary of Fit

Analysis of LogLikelihood

Source	DF	-LogLikelihood
Model	1	0.07505
Error	165	115.67754
C Total	166	115.75259

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	0.150	0.6984
Pearson	0.150	0.6985

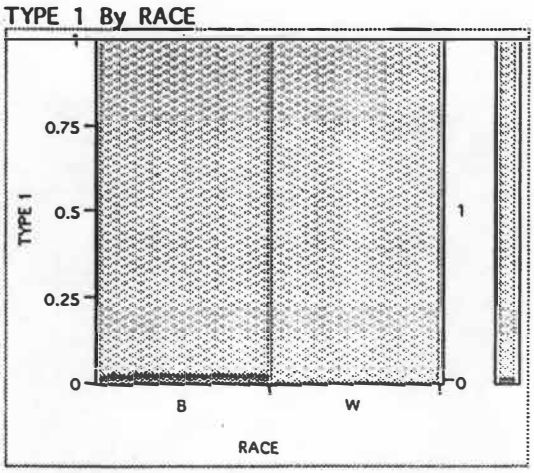
Response Counts

TYPE 1	B	W	Total
B	41	43	84
NB	43	40	83
	84	83	167

Response Profiles

TYPE 1	B	W	All
B	0.4881	0.5181	0.5030
NB	0.5119	0.4819	0.4970
	84	83	167

FIG. 11: C6 response profiles with graphical representation for type of spinous process and bifid/non-bifid classification by race.



Summary of Fit

Analysis of LogLikelihood

Source	DF	-LogLikelihood
Model	1	1.374099
Error	162	9.427095
C Total	163	10.801193

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	2.748	0.0974
Pearson	1.976	0.1598

Response Counts

TYPE 1	B	W	Total
0	2	0	2
1	81	81	162
	83	81	164

Response Profiles

TYPE 1	B	W	All
0	0.0241	0.0000	0.0122
1	0.9759	1.0000	0.9878
	83	81	164

FIG. 12: C7 response profiles with graphical representation for bifid/non-bifid classification by race.

Table 6: Discriminant classification percentages for predicted race by race.

Vertebra	Race	% Correct	% Incorrect
C2	BLACK	72	28
	WHITE	69	31
C3	BLACK	76	24
	WHITE	73	27
C4	BLACK	78	22
	WHITE	73	27
C5	BLACK	78	22
	WHITE	75	25
C6	BLACK	80	20
	WHITE	73	27
C7	BLACK	77	23
	WHITE	72	28

A slightly better classification rate was achieved for sex in C2-C7 (Table 7). Once again, depending on the vertebra used, females were correctly classified 74%-85% of the time, and males were correctly classified 69%-78% of the time. The narrower group classifications were not predicted with the same accuracy (Table 8). Correct group classification ranges were as follows: (1) 43%-82% for black females; (2) 25%-55% for black males; (3) 38%-61% for white females; and (4) 66%-81% for white males. It was not surprising that the results for group classification were best for white males and black females, since they were shown through canonical analysis to be the farthest apart by size.

Table 7: Discriminant classification percentages for predicted sex by sex.

Vertebra	Sex	% Correct	% Incorrect
C2	FEMALE	83	17
	MALE	77	23
C3	FEMALE	81	19
	MALE	77	23
C4	FEMALE	77	23
	MALE	75	25
C5	FEMALE	74	26
	MALE	69	31
C6	FEMALE	81	19
	MALE	73	27
C7	FEMALE	85	15
	MALE	78	22

Table 8: Discriminant classification percentages for predicted group by group.

Vertebra	Group	% Correct	% Incorrect
C2	BF	43	57
	BM	55	45
	WF	61	39
	WM	74	26
C3	BF	70	30
	BM	55	45
	WF	51	49
	WM	81	19
C4	BF	82	18
	BM	41	59
	WF	44	56
	WM	77	23
C5	BF	77	23
	BM	25	75
	WF	38	62
	WM	68	32
C6	BF	76	24
	BM	33	67
	WF	38	62
	WM	66	34
C7	BF	70	30
	BM	53	46
	WF	47	53
	WM	74	26

CHAPTER 5

DISCUSSION AND CONCLUSIONS

Gross morphological and metric variation of the cervical spine with respect to race and sex have been investigated. Past research, in this area, has usually centered on the racial variability in the cervical spine, with little attention paid to differences attributed to sex (Allbrook, 1955, Cunningham, 1886, Lanier, 1939, Shore, 1931, Trotter, 1929). This may have been due to the lack of documented female skeletal materials available to researchers during the predominant time of intensive spinal research. This research has attempted to: (1) discriminate groups, race and/or sex using metric variation analyses; and (2) estimate the strength of the relationship between cervical spine gross morphological types (Shore, 1931) and race. A pooled sample (N=174) was used for these analyses comprised of individuals from the William M. Bass Collection (N=86) and the Terry Anatomical Collection (N=88).

The findings of this research indicate that race and sex classifications can be discriminated with accuracy through metric analysis of the cervical vertebrae for this sample. Blacks were correctly classified with a 72%-80% accuracy rate; while, whites achieved a 69%-75% accuracy rate. The classification rates for sex were slightly higher with 74%-85% of the females correctly classified and 69%-78% of the males correctly classified.

Group classifications were found to be accurate for white males and black females in this sample. Black male and white female classification levels were found to be low to moderate. The small sample size of this study may have been a factor in the misclassification of groups. For forensic purposes, the use of these classifications is unclear, since all groups were not accurately discriminated. This analysis would need to be fine-tuned and studied on a larger sample of individuals in order to further test its accuracy and therefore determine its usefulness as a possible forensic identification tool.

The strength of the relationship between spinous process types (bifid and non-bifid) and race was found to be significant at the C3, C4, and C5 level for this sample. The findings showed that at these levels, spinous processes of whites had a higher incidence of bifid types (bifurcate and cleft) and spinous processes of blacks had a higher incidence of non-bifid type spines (acute, obtuse, pediculate, and clavate). These findings are in agreement with observations made by Allbrook (1955), Cunningham (1886), Lanier (1939), and Shore (1931). The sample studied by Shore (1931) consisted of South African Negroids (Bantu and Bushman) and was found to have a considerably lower percentage of bifid spines (7% of the Bushman sample/21% of the Bantu sample) than the Negroids sampled in this study. The Negroid sample used in this research is composed of individuals from two collections. The individuals from the Bass

Collection could considered modern American Negroids; therefore, alluding to possible intermixture with Caucasoids, Amerindians and/or other groups. The Negroid sample from the Terry collection are descendants of original slaves, and show characteristics ranging from Negroid to varying degrees of Caucasoid-Negroid, and possibly Amerindian (Mongoloid) intermixture (Lanier, 1939). This blending of traits may be partially responsible for the higher percentages of Negroids in this sample possessing bifid spines. Small sample size on the part of both studies may have also played a role.

The results of this study show that the null hypothesis, that gross morphological and/or metric variation is not correlated with race and/or sex in the cervical spine (C2-C7), must be rejected. The test hypothesis, that gross morphological and/or metric variation of the cervical spine (C2-C7) is correlated with race and/or sex differences, must,consequently, be accepted.

The functional question of why these gross morphological and metric differences are apparent must also be addressed. The weak normal-anatomical foundation of the cervical spine complicates this question, since there is no definitive "normal" description of the elements of this region.

The following is provided as an example of the conflicting opinions surrounding the development of the cervical spinous processes. It is known that secondary ossification centers appear at the tips of the spinous processes around the age of 16 (Bailey, 1974; Junghanns, 1971; Sherk and Parke, 1983). According to Bailey

(1974), these centers can either be paired or singular coinciding with a bifid or non-bifid spinous process. Junghanns (1971) states that there are always two ossification centers present, thus producing the bifid spine formation. In contrast to these observations, Sherk and Parke (1983) state that only a singular ossification center is present at the tip of the spinous process, yet later mention bifidity as a normal characteristic of C2-C5. Variability in the occurrence of the secondary ossification centers at the tips of the spinous processes seems to point to a possible underlying genetic foundation for this variation.

Some scholars suggest the bifid nature of the spines provides a functional role by providing a greater surface area for the attachment of ligaments and muscles. As an example, they point to the highly bifid condition of C2 (Gray, 1989; Sherk and Parke, 1983). While this appears to be a valid observation there exists a paucity of relliable evidence for this conclusion.

The most discernible difference between sexes is the size of the vertebrae. Female vertebrae, on average, are proportionally smaller than those of males (Thieme and Schull, 1957; Tortora, 1989). Males exhibit greater vertebral body elongation than females, which is usually cited as the main factor contributing to measurable sex differences (Bench, 1963; Trotter, 1929). As a side note some scholars have suggested that size variations may be attributable to other factors. For instance, Todd and Pyle (1928) researched the effects of maceration and drying practices on a small sample (N=20)

of black and white vertebral columns. The results of this study concluded that the shrinkage rates in vertebral columns are unequal, with the vertebral bodies shrinking 1.5% on the ventral aspect and 2.5% on the dorsal aspect and at the mid-centrum diameter. Due to Todd and Pyle's small sample size and the low rates of shrinkage, for the purposes of this study, the effects of curatorial practices was ruled out as a meaningful contributor to size variation.

This research has addressed the objectives set forth, but at the same time, it was unable to fully determine the source(s) of the gross morphological differences apparent in the cervical spinous processes. These differences are deserving of further research into their causation and function. The area of cervical vertebrae metric variation would benefit from the inclusion of additional measurements and a larger sample size for testing.

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APPENDICES

APPENDIX A

APPENDIX A: Measurement means for C2-C7 by group.

C2

Group	N	Variable	Mean	Std. Dev.	Min.	Max.
Black	37	Min. width of s.p.	12.49	3.08	05.00	18.30
Female	37	Max. width of s.p.	15.45	2.41	10.90	20.90
	38	Max. length of s.p.	15.74	1.80	11.70	19.70
	37	Centrum ht.	21.97	2.59	17.60	32.70
Black	44	Min. width of s.p.	13.86	3.60	07.60	23.40
Male	44	Max. width of s.p.	17.68	3.61	11.00	25.40
	44	Max. length of s.p.	17.29	2.27	12.90	22.00
	44	Centrum ht.	23.38	1.63	20.40	29.10
White	44	Min. width of s.p.	13.86	3.60	07.60	23.40
Male	44	Max. width of s.p.	17.68	3.61	11.00	25.40
	43	Max. length of s.p.	17.29	2.27	12.90	22.00
	43	Centrum ht.	23.38	1.63	20.40	29.10
White	38	Min. width of s.p.	11.41	3.14	05.80	19.40
Female	38	Max. width of s.p.	14.68	2.83	10.00	21.40
	38	Max. length of s.p.	14.82	1.96	10.90	18.30
	38	Centrum ht.	22.60	2.12	18.50	28.00

C3

Group	N	Variable	Mean	Std. Dev.	Min.	Max.
Black	37	Min. width of s.p.	05.10	2.73	01.00	12.90
FemalE	37	Max. width of s.p.	07.56	2.56	02.80	12.90
	37	Max. length of s.p.	14.58	2.45	10.40	20.00
	37	Centrum ht.	12.61	1.37	10.70	17.30
	37	Angle of s.p.	35.04	6.73	24.00	52.50
Black	44	Min. width of s.p.	04.70	2.72	01.30	11.30
Male	44	Max. width of s.p.	07.89	3.65	03.00	16.20
	44	Max. length of s.p.	14.95	3.67	05.80	21.60
	44	Centrum ht.	13.93	1.01	11.40	16.10
	42	Angle of s.p.	05.62	7.79	15.00	50.00
White	42	Min. width of s.p.	7.44	2.46	02.20	13.40
Male	42	Max. width of s.p.	11.52	3.70	04.70	22.00
	42	Max. length of s.p.	16.20	2.32	11.00	21.00
	44	Centrum ht.	15.46	0.98	13.30	18.00
	42	Angle of s.p.	40.10	8.38	20.00	57.00
White	37	Min. width of s.p.	07.28	3.10	02.30	14.40
Female	37	Max. width of s.p.	10.42	3.01	05.00	17.00
	38	Max. length of s.p.	14.14	2.80	09.50	20.40
	38	Centrum ht.	13.26	1.24	10.40	17.00
	38	Angle of s.p.	39.41	8.52	21.00	68.00

APPENDIX A, CONT.: Measurement means for C2-C7 by group.

C4

Group	N	Variable	Mean	Std. Dev.	Min.	Max.
Black	39	Min. width of s.p.	05.48	1.90	01.60	10.40
Female	39	Max. width of s.p.	08.59	2.43	04.80	14.20
	39	Max. length of s.p.	14.67	2.35	10.00	20.50
	39	Centrum ht.	12.07	0.70	10.30	14.00
	39	Angle of s.p.	35.35	5.40	22.00	45.00
Black	46	Min. width of s.p.	06.18	3.09	01.60	13.90
Male	46	Max. width of s.p.	10.23	3.16	03.30	16.50
	47	Max. length of s.p.	15.10	3.00	07.70	21.70
	46	Centrum ht.	13.57	1.12	11.40	15.60
	47	Angle of s.p.	36.34	9.07	20.00	62.00
White	43	Min. width of s.p.	08.88	2.51	03.75	15.00
Male	43	Max. width of s.p.	13.92	3.56	05.20	22.60
	43	Max. length of s.p.	15.88	3.91	10.00	24.70
	44	Centrum ht.	15.07	1.11	13.20	17.60
	44	Angle of s.p.	38.97	8.00	25.00	56.00
White	37	Min. width of s.p.	05.48	1.90	01.60	10.40
Female	36	Max. width of s.p.	11.52	3.21	04.00	17.40
	37	Max. length of s.p.	14.36	3.41	10.00	24.70
	38	Centrum ht.	13.04	1.04	11.00	16.00
	37	Angle of s.p.	39.00	6.98	21.00	52.00

C5

Group	N	Variable	Mean	Std. Dev.	Min.	Max.
Black	39	Min. width of s.p.	04.94	1.68	02.50	08.90
Female	39	Max. width of s.p.	08.28	2.12	05.00	14.00
	39	Max. length of s.p.	16.02	3.50	10.30	25.00
	39	Centrum ht.	12.07	1.10	10.20	16.80
	39	Angle of s.p.	33.88	8.11	14.00	54.00
Black	45	Min. width of s.p.	05.42	2.03	01.90	11.40
Male	45	Max. width of s.p.	09.63	2.85	04.50	16.00
	45	Max. length of s.p.	16.01	5.04	02.10	33.00
	45	Centrum ht.	13.37	1.33	11.30	16.80
	44	Angle of s.p.	34.25	8.37	21.00	53.00
White	45	Min. width of s.p.	07.16	2.63	00.70	14.80
Male	45	Max. width of s.p.	12.37	3.08	06.25	20.50
	45	Max. length of s.p.	16.69	3.21	10.40	24.20
	46	Centrum ht.	14.77	1.17	12.00	17.70
	46	Angle of s.p.	39.20	8.94	18.00	55.00
White	39	Min. width of s.p.	07.20	2.37	03.20	12.50
Female	39	Max. width of s.p.	11.39	2.46	06.50	17.00
	38	Max. length of s.p.	14.96	3.12	10.10	22.90
	37	Centrum ht.	13.16	1.07	10.40	15.80
	38	Angle of s.p.	39.26	7.04	21.00	49.00

APPENDIX A, CONTD.: Measurement means for C2-C7 by group.

Group	N	Variable	C6 Mean	Std. Dev.	Min	Max.
Black	38	Min. width of s.p.	03.95	0.96	01.90	06.20
Female	38	Max. width of s.p.	08.08	1.91	03.50	13.00
	38	Max. length of s.p.	20.49	4.92	06.90	30.00
	39	Centrum ht.	12.08	0.76	10.20	13.90
	39	Angle of s.p.	32.40	6.74	20.00	49.00
Black	45	Min. width of s.p.	04.64	1.24	02.60	08.40
Male	45	Max. width of s.p.	09.51	2.03	06.30	16.60
	46	Max. length of s.p.	24.63	6.17	13.40	42.00
	46	Centrum ht.	13.31	1.37	11.20	17.00
	46	Angle of s.p.	29.10	7.85	15.00	43.00
White	45	Min. width of s.p.	05.24	1.57	03.00	10.00
Male	45	Max. width of s.p.	10.76	2.36	06.00	19.00
	45	Max. length of s.p.	24.14	6.10	13.00	36.20
	44	Centrum ht.	14.67	1.04	12.00	17.00
	45	Angle of s.p.	35.10	8.31	20.00	50.00
White	38	Min. width of s.p.	05.12	1.55	02.20	09.90
Female	38	Max. width of s.p.	09.03	1.96	03.70	12.90
	38	Max. length of s.p.	14.96	3.12	10.10	22.90
	37	Centrum ht.	21.92	4.71	12.90	30.60
	37	Angle of s.p.	34.22	7.52	21.00	50.00

Group	N	Variable	C7 Mean	Std. Dev.	Min.	Max.
Black	37	Min. width of s.p.	05.33	0.89	03.90	07.80
Female	37	Max. width of s.p.	09.50	1.53	07.00	13.20
	37	Max. length of s.p.	28.78	4.71	12.00	34.90
	37	Centrum ht.	13.41	0.95	10.80	15.80
	37	Angle of s.p.	27.16	6.87	13.00	43.00
Black	45	Min. width of s.p.	06.54	1.64	03.90	13.10
Male	45	Max. width of s.p.	10.86	2.14	06.70	16.50
	45	Max. length of s.p.	33.85	3.93	15.00	40.80
	45	Centrum ht.	14.61	1.20	12.30	18.00
	45	Angle of s.p.	25.01	6.21	15.00	41.00
White	45	Min. width of s.p.	06.42	1.08	04.50	09.80
Male	45	Max. width of s.p.	11.29	2.50	07.40	18.70
	45	Max. length of s.p.	35.07	3.50	27.00	43.00
	44	Centrum ht.	15.90	0.94	13.40	18.00
	43	Angle of s.p.	31.51	6.23	19.00	45.00
White	36	Min. width of s.p.	05.68	0.98	04.20	08.00
Female	36	Max. width of s.p.	09.31	1.28	07.00	12.00
	36	Max. length of s.p.	31.27	2.45	27.20	36.80
	36	Centrum ht.	14.39	0.99	11.80	16.20
	36	Angle of s.p.	30.61	6.07	21.00	46.00

APPENDIX B

APPENDIX B: Definitions of cervical vertebrae type classifications (Shore, 1931:483).

A. BIFID
1) BIFURCATE
2) CLEFT

B. NON-BIFID
1) ACUTE
2) OBTUSE
3) PEDICULATE
4) CLAVATE

BIFURCATE: Divergence of the sections (alae) of the spinous process. Must be at least 1 mm. deep.

CLEFT: The sections (alae) of the spinous process do not diverge - parallel to one another. Must be at least 1 mm. deep.

ACUTE: Flat-sided spinous processes that terminate by tapering to a point. They are slender and long compared to other non-bifid spines, being often over a millimeter in length

OBTUSE: Blunt-ended spinous processes. These irregular bony prominences show no differentiation for attachment of muscle or ligament. They are often pyramidal or conical in shape, but seldom attain the length of a centimeter.

PEDICULATE: Stud-like spinous processes characterized by a short pedicle, which separate a blunt expanded dorsal end from the point of attachment. May attain one centimeter in length.

CLAVATE: Long and club-shaped spine, having an elongated neck which tapers to the middle, both from the point of attachment and from the dorsal termination. This description applies almost universally to the prominent C7 spinous process.

APPENDIX C

APPENDIX C: Definitions of measurements taken on cervical vertebrae.

MINIMUM WIDTH OF SPINE: MEASURED AT THE MINIMUM POINTS ON THE LATERAL EDGES OF THE SPINE (VERNIER CALIPERS).

MAXIMUM WIDTH OF SPINE: MEASURED AT THE MAXIMUM POINTS ON THE LATERAL EDGES OF THE SPINE (VERNIER CALIPERS).

MAXIMUM LENGTH OF SPINE: MEASURED FROM THE MOST DISTAL POINT OF THE SPINOUS PROCESS TO THE JUNCTION OF THE LAMINAE ALONG THE MIDLINE. (VERNIER CALIPERS)

CENTRUM HEIGHT (C3-C7): MEASURED ALONG THE MIDLINE OF THE CENTRUM OF THE VERTEBRAE; CALIPERS GRIP THE BODY ALONG THE SUPERIOR AND INFERIOR SURFACES (VERNIER CALIPERS).

CENTRUM HEIGHT (C2): MEASURED FROM THE INFERIOR BORDER OF THE CENTRUM TO THE POINT OF FUSION BETWEEN THE ODONTOID AND CENTRUM. NOTE: THIS AREA IS DELIMITED IN ABOUT ONE-THIRD OF NORMAL ADULTS BY A REMNANT OF CARTILAGINOUS TISSUE (VERNIER CALIPERS).

ANGLE OF SPINAL INCLINATION: MEASUREMENT OF THE ANGLE BETWEEN THE SUPERIOR SURFACE OF THE CENTRUM AND THE SUPERIOR EDGE OF THE SPINOUS PROCESS (PROTRACTOR WITH STRAIGHT-EDGE/READING ARM ATTACHMENT).

APPENDIX D

APPENDIX D: Recording sheet used for cervical vertebra measurements.

Colllection: Age: Race: Sex:

IN MM.

Vert. #	Type of S.P. (After Shore)	Min. Width of S.P.	Max. Width of S.P.	Max. Length of S.P.	Angle of S.P.	Body Ht.
2					N/A	
3						
4						
5						
6						
7						

Comments:

VITA

Gwendolyn M. Haugen was born in Fargo, North Dakota on February 22, 1968. She grew up in St. Louis, Missouri, and graduated from Lindbergh High School in 1986.

The following fall she entered Southwest Missouri State University, in Springfield, Missouri. In the fall of 1988, she enrolled at the University of Missouri-Columbia as a journalism major. During this time the author became interested in the field of anthropology and began to work under Dr. Sam Stout at the Human Identification Laboratory at the University. In December of 1990, the author graduated with a Bachelor of Arts degree in Anthropology. From here she enrolled as a master's student in anthropology at the University of Tennessee, Knoxville. During this time she participated as a member of the Forensic Response Team.

The author is currently employed in the field of public health research as a Study Manager with Battelle/SRA - St. Louis.