Sex Determination Using the Petrous Portion of the Temporal Bone: A Validation Study of Three Cranial Techniques Using Computed Tomography (CT) Scans

by

Jennifer A Morgan

A Thesis submitted to the Faculty of Graduate Studies of

The University of Manitoba

in partial fulfillment of the requirements of the degree of

MASTER OF ARTS

Department of Anthropology

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THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES
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ABSTRACT

This study reports on the validation of three previously published methods of sex determination for the petrous portion of the temporal bone using computed tomography (CT) scans. The objectives of this study were to evaluate the lateral angle (Akansel et al., 2008; Graw et al., 2005; Norén et al., 2005), diameter (Lynnerup et al., 2006), and length methods (Papangelou 1975) for the internal acoustic canal in accurately determining the sex of human skeletal remains using image-based measurements. The mean differences for all of the measurements did not reach statistical significance ($p < 0.05$) and the sex differences reported for the previous cadaveric studies (Akansel et al., 2008; Graw et al., 2005; Lynnerup et al., 2006; Norén et al., 2005; Papangelou 1975) were not substantiated here; however, the consistency in the means and ranges of measurements between the current study and the previous research suggests that computerized tomography (CT) is capable of reproducing direct anatomic measurements of the skull.

KEYWORDS: Sex determination, petrous portion, internal acoustic canal, computed tomography (CT)

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Chapter I: Introduction

An accurate determination of sex is relied upon in a number of osteological contexts, including both forensic and archaeological investigations (Mays and Cox, 2000; Rogers, 2005; Walsh-Haney et al., 1999; Wienker, 1983). Several factors influence the accuracy of sex determination from adult skeletal remains. First, many of the anatomical differences between the skeletal elements of males and females are not significantly pronounced. In terms of skeletal dimensions, males and females differ only by approximately 8% (Krogman, 1962; Mays and Cox, 2000; Wienker 1984). Secondly, the accuracy of traditional morphological and metric approaches to sex determination relies on a high degree of preservation and skeletal completeness, specifically of sexually dimorphic elements of the skull and pelvis. The main challenge associated with these approaches is that the accuracy and confidence in the determination of sex decline proportionately to the completeness of the remains (Holland, 1986; Rogers, 2005; Uysal et al., 2005). This can be problematic for both palaeodemographic studies as well as forensic cases where human skeletal remains are, more often than not, incomplete and/or highly fragmentary (Kelley, 1979; Uysal et al., 2005). Therefore it has become of increasing importance in human osteology and forensic anthropology to develop methods for sexing human remains that do not rely on the presence of multiple and/or intact skeletal elements.

The primary goal of this research is to validate and refine several methods of sex determination for a skeletal element with significant taphonomic survivability, specifically the petrous portion of the temporal bone. This element has been known to survive not only fragmentation, but also the high temperatures of cremation and intentional burning (Lynnerup et al., 2006; Norén et al. 2005; Schutkowski, 1983; Wahl and Graw, 2001). Thus, a better understanding of the sex differences in this bone will be important for future anthropological analyses of skeletal remains.

The objectives of this study are to determine the reliability of three previously developed metric techniques of sex determination for the internal acoustic canal, located within the petrous bone. The techniques to be assessed will include measurements of the lateral angle of the internal acoustic canal (Graw et al. 2005; Norén et al. 2005), the diameter of the canal opening (Lynnerup et al. 2006), and the lengths of the lateral and medial walls of the canal (Papangelou, 1975). The use of these techniques as diagnostic tools for sex determination has been discussed in recent forensic and anthropological literature and has been demonstrated to reliably predict the sex of human skeletal remains (Akansel et al., 2008; Lynnerup et al., 2006; Norén et al. 2005).

Chapter II provides a review of the wider topic of sex determination as it applies to the human skeleton in general. This discussion includes a review of the various skeletal elements which display observable and measureable sex differences, as well as the morphological, metric, and statistical techniques applied to determine sex from these differences. This overview provides the context and literary background for validating the three previously published methods of sex determination in the present study. The final section of this chapter outlines the role of advanced medical imaging and computer-based analyses in anthropological investigations.

Chapter III includes a description of the materials and methods used to fulfill the objectives of the present study. This section includes a description of the sample of CT scans provided by the Department of Forensic Medicine from the University of

Copenhagen, Denmark, as well as an explanation for the selection of the specific cases examined. Methodologies for each of the three cranial features of interest are presented along with the specific computer-based measurement techniques developed for examining the sexual dimorphism of these features using the Materialise MIMICS version 12.1 imaging software.

Chapter IV presents the results of the statistical analyses performed on the data collected from the current CT sample. These results include analyses of left and right side differences, and sex differences for each of the variables considered, including the lateral angle, diameter measurements, and the lengths of the lateral and medial walls of the internal acoustic canal. Relationships between each of the cranial measurements and age were also examined using Pearson's correlation coefficient statistics and by splitting the larger sample into two sub-samples, younger (<50) and older (50+), to determine if age has any effect on the outcome of the analyses. A brief section on the results of a logistic regression analysis is also included.

Chapter V provides a detailed discussion of the methodological issues encountered and the potential reasons for the specific results observed from the statistical analyses of each of the three traits of the petrous portion. The implications and limitations of this study are also considered along with recommendations for future research projects. Finally, concluding remarks on the findings from this research are offered in the conclusions section of this chapter.

It is anticipated that the refinement of the previously published methods in this study will allow for a better understanding of the sexual dimorphism of the petrous portion and may increase the confidence of the osteologist in determining skeletal sex from highly fragmentary and/or cremated human remains in archaeological and forensic situations. Also, it is expected that the results of this research will provide many benefits to skeletal sex determination within the study of human osteology, as well as introduce new possibilities for the analysis of fragile or fragmentary human remains. Furthermore, it is anticipated that this study will illustrate the importance of computer-assisted analyses for improving both the efficiency and accuracy of measurements for the determination of sex through the standardization in methodology offered by computerized measurement programs.

Chapter II: Literature Review

Human osteology, the study and analysis of human skeletal remains, has provided valuable insights into the past and present of humankind. From the reconstruction of past living populations to more contemporary issues of positive identification, the application of methods developed for the study of human osteology have greatly increased our understandings of human evolution, variation, and individuality (Bass, 1995; Buikstra and Ubelaker, 1994; Mays and Cox, 2000). In the past two decades, the fields of human osteology and physical anthropology have witnessed a number of innovative advancements for the analysis of human remains. Traditional measurements and observations of skeletal remains in both archaeological and forensic contexts are constantly being refined and used in new ways (Akansel et al., 2008; Cavalcanti et al., 2004; Metcalfe, 2008; Uysal et al., 2005; Weber et al., 2001). Advances in technologies such as X-ray Computed Tomography (CT) scanning, Magnetic Resonance Imaging (MRI), computer-based anthropometry, and biochemical analyses are answering questions that could not have been answered ten years ago, and are significantly improving the accuracy of skeletal analyses (Dedouit et al., 2007; Smith et al., 2002; Weber et al., 2001).

Creating a biological reconstruction, or profile, from skeletal or decomposing human remains is one of the more difficult tasks in human osteology in general and forensic anthropology specifically (Günay and Altinkök, 2000). When presented with human skeletal remains the osteologist is typically able to approximate four biological factors with varying accuracies: age, sex, stature, and ancestry (Buikstra and Ubelaker, 1994; Scheuer, 2002; Ubelaker, 2000). According to Wienker (1984), of these factors, the determination of sex can usually be made with the greatest degree of accuracy when the skeleton is complete or nearly all of the bones comprising the skeleton are present. Saunders and Yang (1999:36) have stated that sex has been considered one of the easiest biological characteristics to assess from the human skeleton since there are only two possible choices, male or female.

In addition, a thorough knowledge of sex differences in human skeletal remains is also of fundamental importance to anthropological and scientific studies on human growth and evolution. Of the four major demographic factors of interest to the osteologist, sex appears to have been accorded the most weight, being the most studied aspect of skeletal demography in anthropology with almost every bone of the human skeleton examined and analyzed to this effect (Novotný et al., 1993).

For the human osteologist and physical anthropologist the term 'sex', not gender, refers to the biological qualities that serve to differentiate males and females (Mays and Cox, 2000; Ubelaker, 2000). According to Mays and Cox (2000:117) this difference is fundamentally chromosomal, "females having two X chromosomes and males an X and a Y". Thus, the developmental differences between males and females are the result of hormone-related changes that are linked to this chromosomal distinction. Sexual dimorphism thereby results through the response of the body's tissues, including bone, to circulating hormones which vary between the biological sexes (Mays and Cox, 2000; Wilson et al., 1981).

Sex determination from the skeleton relies heavily on the presence of observable and recordable differences in skeletal morphology between males and females; these differences, or definitive secondary sex characteristics, do not manifest themselves on the skeleton until the adolescent period, also known as puberty (Bass, 1995; Mays and Cox, 2000; Rogers, 2005; Walsh-Haney et al., 1999). It is important to note that up to the ages of fifteen to eighteen years, sexual dimorphism on the pre-pubertal skeleton is slight, making sex determination for the skeletal remains of sub-adults extremely difficult (Bass, 1995; Mays and Cox, 2000).

Sexual dimorphism in the skeleton results from a difference in the rate and duration of growth between the sexes, and is largely due to the divergence of growth patterns between males and females both prior to and during adolescence. Adolescent growth generally occurs approximately 2 years earlier in females than in males, with males having a longer and more intense growth spurt (Humphrey, 1998; Rogers, 2005). This difference in the duration of growth between the sexes is responsible for the size differences that are observable in certain skeletal elements (Rogers, 2005); however, it should also be noted that sexual dimorphism also occurs, although very slightly, in skeletal elements that complete their growth prior to adolescence, such as the clavicle, pelvis, and glenoid cavity of the scapula, and are directly related to sex differences in growth rates rather than duration (Humphrey, 1998). As a consequence of these two variables, rate and duration of growth, sexual dimorphism manifests in the human skeleton in two primary forms: size and architecture (Byers, 2005; Scheuer, 2002).

Where size differences play a role in sexual dimorphism males, on average, tend to be larger than females with skeletal elements that are bigger and more robust. Architectural differences, on the other hand, are directly related to requirements for childbirth. The male pelvis is primarily constructed to support bipedalism whereas the female pelvis is adapted in size and shape to allow for bipedalism as well as the birthing of infants (Byers, 2005; Scheuer, 2002). Because of its distinctive adaptive differences between males and females, it has been agreed upon in the literature that the bony elements of the pelvis provide the most reliable indicators for sex determination (Bass, 1995; Krogman and İşcan, 1986; Phenice, 1969; Scheuer, 2002; Schutkowski, 1993; Walsh-Haney et al., 1999). It has also been generally accepted that the second most sexually dimorphic element of the skeleton is the skull, followed by the long bones and other postcranial, non-pelvic, elements. Many researchers have claimed accuracies of 90-100% when sexing the entire skeleton (Krogman, 1962; Krogman and İşcan, 1986; Stewart, 1979), 90-98% from the pelvis alone, 80-90% from the skull alone, 98% for the skull and pelvis together, and 80-90% with only the long bones (Byers, 2005; Günay and Altinkök, 2000; Mays and Cox, 2000; Krogman and İşcan, 1986; Scheuer, 2002).

According to Novotný et al. (1993), to be considered very reliable, sexually dimorphic traits of the skeleton must correspond with actual sex in more than 60% of cases, and misclassify sex in no more than 10%. To be considered reliable, traits must allow correct sex assignment in more than 50% of cases with a misclassification of no more than 15%. Traits that are of low reliability enable 50% accuracy, and traits which provide an accuracy below 50%, and misclassify sex in more than 20% of cases are considered unreliable for the determination of sex (Novotný et al., 1993).

DETERMINATION OF SEX

There are a number of available methods that have been developed for determining the sex of human skeletal remains in both archaeological and forensic contexts. Indicators of sex can be discerned through the analysis of selected morphological features that differ between males and females, metric techniques for dimorphic dimensions, and statistical approaches such as discriminant function and logistic regression analysis (Buikstra and Ubelaker, 1994; Rösing et al., 2007; Stewart, 1979; Wienker, 1984). When attempting to establish sex it is essential to perform a thorough examination of the entire skeleton using morphological and/or metric techniques; however, the reliability of sex determination as well as the utility of the methods employed are dependent upon the completeness of the remains (Mays and Cox, 2000; Rogers, 2005). In order to achieve the most accurate estimation of sex all available methods of analysis, using as many skeletal features as possible, should be employed to reduce the probability of error in results (Bass, 1995; Buikstra and Ubelaker, 1994; Byers, 2002; Krogman and İşcan, 1986; Mays and Cox, 2000; Rogers, 2005).

Training manuals available in human osteology and forensic anthropology have advocated the use of a combination of approaches that bring together both morphological and metric sexing techniques (Bass, 1995; Buikstra and Ubelaker, 1994; Byers, 2002; Krogman and İşcan, 1986; White, 2000). However, there has been a long standing debate in the literature over whether morphological or metric traits are more effective at achieving an accurate determination of sex (Novotný et al., 1993; Rogers, 2005).

Morphological techniques, or visual approaches, for sexing the human skeleton are based upon observations, rather than measurements, of both the size and structural differences between males and females that are observable on specific skeletal elements (Phenice, 1969; Rogers, 2005). Morphological techniques of sex determination are generally limited to three main skeletal structures and include the pelvis (Phenice, 1969; Rogers and Saunders, 1994), skull (Krogman and İşcan, 1986), and distal humerus

(Rogers, 1999); however, the benefits of using visual techniques over metric approaches emanates from both their ability to be applied to fragmentary skeletal remains where metric methods often fail, as well as their rapidity of use when compared to the time consuming process associated with obtaining measurements and performing statistical analyses (Bruzek, 2002; Phenice, 1969; Rogers, 2005). Morphological sexing techniques have been used by many investigators including Hrdliçka (1952), Stewart (1954), Krogman (1962), and Phenice (1969) and continue to be developed and reviewed in more recent research such as that done by Bruzek (2002), Rogers (2005), and numerous others. Although morphological techniques for sex determination have several advantages over metric methods, they too suffer from a number of limitations. Firstly, high levels of accuracy in assigning sex are dependent upon observer experience. This means that for the researcher with less osteological experience, visual criteria for sex determination may appear ambiguous, especially in the presence of skeletal remains that display an intermediate morphology with respect to the bony elements indicative of sex (Phenice, 1969). Secondly, since there are many intermediate morphological forms of the skeletal elements with observable sexual dimorphism, rather than two separate absolute male and female forms, visual analyses are much more subjective in nature than metric analyses (Phenice, 1969; Rogers, 2005). The lack of consistency and standardization in the evaluation of morphological traits contributes to the problem of subjectivity with these particular methods. Therefore, although visual methods of sex determination are valued for their efficiency in producing results and their applications to fragmentary skeletal material, their subjectivity makes them less desirable in cases, especially forensic, where objectivity and a high degree of accuracy and confidence in results is extremely important (Rogers, 2005).

Metric methods of sex determination have the benefit of relying on standard measurements of specific skeletal landmarks and are considered to be more objective than morphological methods (Rogers, 2005; Stewart, 1979). The standardization of measurements and location of specific bony landmarks make metric methods much easier to reproduce and they generate much lower levels of intra- and inter-observer error than their morphological counterparts (Novotný et al., 1993; Rogers, 2005). The types of metric methods employed by the anthropologist vary from simple linear measurements to indices, the ratio between two bony dimensions selected to express the shape of a bone, and statistical analyses commonly used to evaluate groups of measurements (Stewart 1979). The accuracy of metric methods varies depending on the skeletal element being analyzed and ranges from very low levels of accuracy to better than 90% in some cases (Giles and Elliot, 1963; Kalmey and Rathbun, 1996; Rogers, 2005). However, metric analyses are not without limitation, and generally suffer from two major restrictions. Firstly, metric analyses depend on the presence of specific skeletal landmarks and therefore, depend on skeletal remains that are relatively complete in order to obtain accurate and appropriate measurements. This makes it difficult to apply many of the metric methods of analysis to fragmentary material (Phenice, 1969; Rogers, 2005). Secondly, many of the formulae used for developing metric techniques have been derived from collections that are not demographically representative of the diversity of modern human populations (Wienker, 1984). Thus, metric techniques change in their accuracy and applicability when they are used to sex skeletal material that are not derived from the reference populations from which the metric formulae were originally developed (Novotný et al., 1993; Rogers, 2005; Wienker, 1984). In attempts to overcome the drawbacks associated with the broad application of population specific formulae, more recent research such as that undertaken by Albanese (2003) has incorporated a wide range of human variability into the development and testing of metric techniques.

Morphological and metric techniques used for sex determination have inherent advantages and disadvantages associated with each; however both share equal importance to osteological research. Although a combination of both techniques is recommended (Bass, 1995; Bruzek, 2002; Buikstra and Ubelaker, 1994; Byers, 2002; Krogman and İşcan, 1986; Rogers, 2005; White, 2000), it is often at the investigator's discretion as to which method is most appropriate for their particular research questions. In the last ten years, researchers have continued to develop and modify metric and morphological methods of sex determination in efforts to increase accuracy and address shortcomings associated with previous methodologies for sex determination in both archaeological and forensic research (Novotný et al., 1993). Although there are currently no perfect methods of determining sex, continued research in this area has significantly improved our knowledge on the sexual dimorphism of the human skeleton.

The Pelvis

Sexual dimorphism in the pelvis is primarily related to functional modifications that allow for successful childbirth in females (Byers, 2005; Mays and Cox, 2000; Stewart, 1979; Wienker, 1984); therefore, the pelvis has been regarded as one of the most reliable and important structures of the human skeleton for the determination of sex

(Krogman and Işcan, 1986; Stewart, 1979). The characteristics of the pelvis in the female skeleton reflect a wider and more open pelvic girdle including an elliptically shaped overall structure with a wide inlet, greater pelvic diameter, and large pelvic outlet. In comparison, the male pelvis has a higher, narrower, heart-shaped structure and tends to be larger in size and more robust in the areas of the iliac crest, ischial tuberosities, and acetabula (Mays and Cox, 2000; Stewart, 1979; Walsh-Haney, 1999; Wienker, 1984). Several other useful morphological observations from the pelvis include the obturator foramen, which is large and oval shaped in males and small and triangular in females, the greater sciatic notch, which is wide in females and narrow in males, and the preauricular sulcus, a depression most often found in females between the sciatic notch and the sacroiliac articulation (Bass, 1995). It is these functional and structural differences that provide the researcher with osteological sex indicators that can be recorded using visual as well as metric techniques (Mays and Cox, 2000; Tague, 1995).

In 1979, Stewart described and discussed six sexually dimorphic features on the complete pelvis which he considered to be most useful for the assessment of sex. These six pelvic features include: the shape of the body of the pubis, inferior pubic curvature, the ventral arc, scars of parturition, the iliac auricular surface, and sacroiliac osteophytosis (Stewart, 1979).

The shape of the body of the pubis, first described by Smith (1939 in Stewart, 1979) and later by Stewart (1979), is a direct result of the enlargement of the pelvic inlet to allow for childbirth in females. The body of the pubis is broader in females, with the inferomedial angle being more prominent than in males. These features, together, result in a rectangular body shape in the female pubis and a more triangular shape in males

(Stewart, 1979; Wienker, 1984). In an investigation by Rogers and Saunders (1994), the accuracy of the shape of the body of the pubis as an individual sex determinant was reported at 86.2%.

In 1889, Cleland was likely the first to describe the presence of the ventral arc, characteristic of the female pelvis, which was examined and described in detail by Phenice (1969) and found to have accuracies ranging from 86.9% (Rogers and Saunders, 1994) to 96% (Sutherland and Suchey, 1991) when considered as a single morphological indicator of sex. As the name suggests, the ventral arc is located on the ventral surface of the pubic bone and is described as a well-defined elevated ridge that extends from the pubic crest and arcs inferiorly to the ischiopubic ramus. This feature is typically absent in the male pelvis (Phenice, 1969; Stewart, 1979; Walsh-Haney et al., 1999).

In addition to an examination of the ventral arc, inferior pubic curvature was first described by Sydney Smith (1939) and later by Stewart (1979) and remains an important indicator of sex on the pelvis (Stewart, 1979; Walsh-Haney et al., 1999). Also known as subpubic concavity or the subpubic angle, this feature of the pelvis is observed only in females and is located immediately below the pubic symphysis in the ramus (Krogman and İşcan, 1986; Phenice, 1969; Stewart, 1979; Walsh-Haney et al., 1999). The concavity of this pelvic feature results in an angle greater than 90° in the female pelvis creating a widening of the pelvic outlet, or the birth canal (Byers, 2005; Rösing et al., 2007). Rösing et al. (2007) have suggested that there is a consensus among many anthropological researchers that the subpubic angle should be given the most consideration, or weighted as the most significant, sexually dimorphic feature when assessing the sex of human remains using the pelvis. However, when used as an individual morphological trait for determining sex, Rogers and Saunders (1994) have reported an accuracy of only 83.8%, significantly lower than the accuracies of other individual traits such as the shape of the sacrum, or the shape of the obturator foramen at 94.1% and 93.8% respectively (Rogers and Saunders, 1994).

According to Stewart (1979), the pit-like scars of parturition, also referred to as dorsal pitting (Bass, 1995; Rogers and Saunders, 1994), are often, but not always, considered to be signs of childbearing and thus, indicative of sex. These pits, often formed in rows, occur in two areas of the pelvis: the dorsal side of the pubic symphysis along the articular surfaces, as well as the preauricular sulci of the ilia (Stewart, 1979; Wienker, 1984). Houghton (1974) explained the occurrence of these pits as the result of a bony reaction to both hormonally mediated changes that occur to the ligaments of the pelvic joints, as well as the stress experienced by these ligaments during pregnancy. The presence of dorsal pitting has traditionally been considered as indicative of the female sex, and their presence is more common in females; however, when analyzed for its reliability as an indicator of sex in a 19th-century cemetery population, dorsal pitting was reported to correctly indicate sex in only 35.7% of cases (Rogers and Saunders, 1994). In more recent literature this pitting has been associated with increasing age, and pelvic size and shape in females as well as in males rather than as markers of childbearing and are no longer thought to be useful indicators of sex (MacLaughlin and Cox, 1989; Mays and Cox, 2000; Scheuer, 2002; Suchey et al., 1979).

The fifth feature, first described by St. Hoyme in 1963, is the iliac articular surface, also referred to as the auricular surface at the sacroiliac joint (Walsh-Haney et al., 1999; Wienker, 1984). This particular feature is located at the point of articulation of the os coxae with the sacrum on the joint surface of the ilium. Although Stewart (1979) lists this feature as one of the six most useful for determining sex using the pelvis, when considered alone the auricular surface has an accuracy of only 73.5% (Rogers and Saunders, 1994). The auricular surface tends to be elevated in females when compared to males, and contributes to the widening of the pelvic inlet (Stewart, 1979; Walsh-Haney et al., 1999). Related to this raised auricular surface, but not mentioned in Stewart's (1979) descriptions of the sexually dimorphic features of the pelvis, is the pre-auricular sulcus, a closed depression in the bone found between the auricular surface and the sciatic notch (Walsh-Haney et al., 1999). Often associated with dorsal pitting, this feature is typically found more often among females (Bruzek, 2002; Rogers and Saunders, 1994; Walsh-Haney et al., 1999), and carries a significantly higher accuracy than the auricular surface at 91.6% (Rogers and Saunders, 1994).

Finally, the last sexually dimorphic feature described by Stewart (1976) is found in individuals over forty years of age when ossification occurs at the sacroiliac joint. The development of osteophytes at the ligament attachments that bridge the ilium and the sacrum can sometimes result in the fusion of the sacroiliac joint, known as sacroiliac osteophytosis. Data collected by Stewart in 1976 indicates that 90% of examined pelves with sacroiliac osteophytosis were male; however, there appears to be no additional published data on the reliability of this feature to accurately predict the sex of skeletal remains. Although Stewart (1976) appears confident in the value of sacroiliac osteophytosis for sexing the pelvis, the overall usefulness and reliability of this particular morphological feature for current research purposes remains questionable.

Perhaps one of the best known visual methods for the determination of sex using the pelvis is the method of Phenice (1969), which uses three sexually dimorphic traits of the os pubis. Preliminary investigations performed by Phenice in 1969 on 275 black and white adult pelvises from the Terry Skeletal Collection indicated that the use of the ventral arc, subpubic concavity, and the medial aspect of the ischio-pubic ramus allowed for an accuracy in excess of 95% for correctly sexing individuals using the os pubis (Phenice, 1969).

The ventral arc and subpubic concavity have been described in detail above. The third structure observed by Phenice (1969), the medial aspect of the ischio-pubic ramus, is located immediately below the pubic symphyseal surface. This feature of the os pubis has a broad and flat structure in males and a narrow and crest-like appearance in females (Phenice, 1969; Kerley, 1977; Krogman and İşcan, 1986). It has been reported that that the ischiopubic ramus has an accuracy of 80% when considered as an individual indicator of sex (Rogers and Saunders, 1994).

Although Phenice (1969) reported an accuracy of 95% in combining these three sexually dimorphic traits of the os pubis, results from later studies using this method have been inconsistent, reporting accuracies ranging from as low as 59% (MacLaughlin and Bruce, 1990) to 96% (Bruzek, 2002; Sutherland and Suchey, 1991). In a study on the accuracy of sex determination using morphological traits of the pelvis, Rogers and Saunders (1994) reported an accuracy of 88% when combining all three traits; however, Sutherland and Suchey (1991) have described that when solely using the ventral arc an accuracy of 96% can be achieved. Several authors have concluded that the reliability of the method of Phenice (1969) is slightly less than those results reported by earlier research, and is probably around 80% (Lovell, 1989; MacLaughlin and Bruce, 1990; Bruzek, 2002). This lack of consistency in the reliability of the aforementioned method may be related to a number of different factors such as a lack of standardization in methodologies, a varying range of observer experience, and/or the subjectivity associated with morphological sexing techniques.

It has also been suggested that in assessing the sexual dimorphism of the pelvis, the entire pelvic bone should be considered rather than restricting analytical observations to the os pubis, which has a very low skeletal survival rate and is usually preserved in only 30% of archaeological collections (Bruzek, 2002, Novotný, 1986). Being the most delicate region of the pelvis, breakage frequently occurs in the pubic region due to a variety of taphonomic factors, leaving only small portions of the os pubis available for analysis (Kelley, 1979). This results in the method of Phenice (1969) being largely ineffective for determining sex when preservation of the pubic region is poor. Although the aforementioned morphological method of determining sex using the os pubis initially produced high degrees of reliability, the fragmentary nature of many archaeological remains has resulted in a great deal research on a number of other sexually dimorphic structures of the pelvis which have significantly higher rates of taphonomic survivability (Bruzek, 2002; Kelley, 1979; Rogers and Saunders, 1994).

In a report on the accuracy of sex determination using17 individual morphological traits that cover various aspects of the entire pelvis, Rogers and Saunders (1994) investigated a sample of 49 adult right and left hip bones and sacra from a 19th-century cemetery sample from Belleville, Canada. In addition to several of the traits previously researched by Phenice (1969) and Stewart (1979), Rogers and Saunders (1994) also considered the shape of the pelvic inlet, true pelvis size and shape, the development of muscle markings, the shape of the obturator foramen, the size and orientation of the acetabulum, the shape of the ilium, the size and shape of the sciatic notch, the shape of the sacrum, the number of sacral segments, and the visibility of the sacroiliac joints.

The authors report (1994) that in combining all of the listed traits an accuracy of 95.9% can be achieved, higher than any accuracy generated by a single pelvic feature. Sacrum shape was the most reliable single indicator of sex with an accuracy of 94.1%. A combination of the shape of the obturator foramen and the ventral arc produced an accuracy of 98%, as did the combination of the shape of the obturator foramen and the true pelvis shape. The shape of the pubis and the shape and size of the acetabulum, combined, produced an accuracy of 96%. These three combinations of individual pelvic traits produced accuracy levels higher than the combination of the entire suite of 17 traits.

In addition to morphological studies of sexual dimorphism, the adult pelvis has also been studied and analyzed both osteometrically and statistically (Krogman and İşcan, 1986). However, because of the difficulty in taking measurements from this bone, there are fewer methods for determining sex using metric measurements of the pelvis (Byers, 2005). One of the earlier and still most widely accepted metric techniques for assessing sex using the os pubis was originally developed by Schultz (1930) and is referred to as the ischiopubic index. This index is derived from measurements of the length of the ischium and pubis from the point at which they meet on the acetabulum (Bass, 1995; Kelley, 1979; Stewart, 1979). This measurement is taken for the purpose of effectively measuring the difference in proportion between male and female pelves and is determined by dividing the length of the pubis by the length of the ischium. This value is then multiplied by 100 to yield an index (Bass, 1995; Stewart, 1979; Wienker, 1984). In general, the pubic bone is longer in females while the ischium is longer in males, resulting in differing indices between the sexes (Kelley, 1979; Schultz, 1930). The success of this metric technique is dependent upon the sexual dimorphism of the ischium as well as the os pubis, which has been well established as an excellent indicator of sex in the anthropological literature (Hanna and Washburn 1953; Kelley, 1979; Krogman and İşcan, 1986; Phenice, 1969; Rogers and Saunders, 1994; Rösing et al., 2007; Stewart, 1979; Sutherland and Suchey, 1991; Walsh-Haney et al., 1999; Washburn 1948). Later tested and popularized by Washburn (1948), the ischiopubic index was found to be a fairly accurate method for assessing sex. When the ancestral group of the skeletal collection is known, the ischiopubic index can produce an accuracy of 91%; however, it was noted that when ancestral group is not known, the accuracy of this technique drops to only 66% (Byers, 2005; Kelley, 1979; Wienker, 1984). This illustrates one of the major caveats to using metric sexing methods. The most accurate results will be achieved in cases where the ancestry of the sample under study is the same as that of the reference sample on which the method was originally developed (Mays and Cox, 2000; Walsh-Haney et al., 1999).

Overall, as a result of the functional modifications required for childbirth, the pelvis is one of the most highly dimorphic elements of the human skeleton, yielding sex determination accuracies between 90-98% (Bruzek, 2002; Byers, 2005; Günay and Altinkök, 2000; Kelley, 1979; Krogman and İşcan, 1986; Mays and Cox, 2000; Rogers and Saunders, 1994; Scheuer, 2002) making it the most preferred element for determining sex in adult skeletal remains.

The Skull

In physical anthropology the skull has traditionally been the single most studied skeletal element and has offered a plethora of knowledge concerning human evolution and variation (Krogman and İşcan, 1986). In the absence of the pelvis, the skull is the second most useful skeletal structure for determining sex (Bass, 1995; Byers, 2005; Walsh-Haney et al., 1999). Like the pelvis, the skull also exhibits sexual dimorphism; however, unlike the architectural differences displayed on the pelvis, the sexually dimorphic characteristics of the skull are related to overall differences in size and robusticity between males and females (Krogman and İşcan, 1986; Walsh-Haney et al., 1999). These differences are a reflection of changes that occur in males at puberty, during which there is a bony response to increasing muscle mass at sites of attachment to the skull. The female skull does not undergo these changes and retains the more gracile juvenile features (Mays and Cox, 2000; Scheuer, 2002; Stewart, 1979).

Like the pelvis, sexual dimorphism in the skull can be assessed using both visual and metric methods. Visual methods for assessing sex from the shape of the skull are valuable tools that are commonly used for two reasons. First, a visual assessment can be completed relatively rapidly and secondly, morphologic, or shape, differences stem from "genetically controlled, sex-linked patterns of growth and development" (Loth and Henneberg, 1996: 474) rather than environmental factors which can affect size, and thus result in metric methods which are extremely population specific (Krogman and İşcan, 1986; Loth and Henneberg, 1996; Walrath et al., 2004).

Krogman (1962) introduced 13 morphological characteristics which he felt were capable of distinguishing sex using the skull. These cranial characteristics included overall size and architecture, supraorbital ridge/glabellar region, orbit shape and position, malar size and rugosity, forehead shape, size of the frontal eminences, palate size and shape, mandibular symphysis and ramus size, size of the parietal eminences, size of the mastoid, the size of the teeth, occipital condyle size, and the shape and size of the nuchal crest. Rogers (2005) evaluated the accuracy of these 13 characteristics using 46 identified individuals from a 19th century cemetery in Belleville, Canada with varying results. In addition to the 13 cranial traits recommended by Krogman (1962), four other cranial traits were included by Rogers (2005): size and shape of the nasal aperture, nasal bone size, extension of the zygomatic arch, and chin form (mental eminence).

Buikstra and Ubelaker (1994) narrowed the list of traits suggested by Krogman (1962) and emphasized five morphological cranial characteristics which they determined were most useful in assessing sex. Using detailed diagrams taken from Acsadi and Nemeskeri (1970), the authors illustrated the range in variation in sexual dimorphism by using a five point scale with female features being represented at the lower end of the range, males at the upper end, and indeterminate features in the middle. Several other well known anthropology and osteology textbooks have also recommended similar lists of visual traits for sex determination on the skull (Bass, 1995; Buikstra and Ubelaker, 1994; Byers, 2005; Hrdliĉka, 1920; Stewart, 1979; White and Folkens, 2005) These traits have become traditional morphological features that continue to be used by modern anthropologists and osteologists to determine the sex of human skeletal remains (Byers, 2005; Rogers, 2005; Williams and Rogers, 2006). These commonly observed features include: the shape and size of the supraorbital ridge/glabellar region, the form of the supraorbital margin, the mental eminence/chin form, size of the mastoid, and the size and shape of the nuchal crest.

The first observation that can be made, prior to further examining more specific morphological features, is the overall size and architecture of the skull in its entirety. This often provides both an initial impression of sex as well as a baseline for examining and comparing other sexually dimorphic traits (Byers, 2005; Rogers, 2005; White and Folkens, 2005). A review of Enlow (1982) reveals the developmental underpinnings related to the expression of sexual dimorphism in the skull. The growth of facial features in the female nears completion around the 13th year, whereas males generally experience a growth spurt which continues through the adolescent period and into early adulthood. This longer period of growth produces more pronounced changes in both the dimensions and proportions of the male skull (Baughan and Demirjian, 1978; Enlow, 1982; Humphrey, 1998; Rogers, 2005).

Using a sample of 73 females (aged 6-15 years) and 47 males (aged 10-18 years), Baughan and Demirjian (1978) examined stature, cranial length, and width for the purposes of studying sexual dimorphism in the growth of the cranium. The authors concluded that females have, on average, a smaller cranium than males even prior to the onset of puberty, which then becomes more pronounced after the extended period of growth observed in males. Although this is the basis for the differences in overall size and rugosity between the sexes, it must be noted that evidence suggests that the cranium continues to grow, albeit slowly, throughout adulthood resulting in the possibility that the overall size of the skull of an older female may begin to closely approximate that of a younger male (Baughan and Demirjian, 1978; Rogers, 2005; Tallgren, 1974). In observing this trait as an individual indicator of sex, size and architecture (rugosity) proved to be consistent in assessing the relative sizes of the other observed traits, but performed poorly in determining sex with an accuracy of only 38% (Rogers, 2005).

The size of the supraorbital ridge, also referred to as the glabellar region, is related to the same growth processes that affect sexual dimorphism in the contour of the forehead and the presence of the frontal eminences (Rogers, 2005). The contour of the forehead retains its juvenile form in the female cranium which is characterized by a high, smooth, and vertical appearance with a rounded, and more pronounced forward protrusion. In contrast, the male forehead is not quite as steep and has a tendency to be more angled and much less rounded in the area of the frontal eminences (Keen, 1959; Krogman, 1962; Krogman and İşcan, 1986; Rösing et al., 2007; Scheuer, 2002; Walsh-Haney et al., 1999). The differences between the sexes in this region of the skull are the result of a differential growth period in the nasomaxillary complex. During this period, the male forehead changes to a more downward position to accommodate a larger frontal sinus as well as the expansion of the supraorbital ridge (Enlow, 1982; Rogers, 2005). As a result, the male face generally exhibits a prominent, bulbous supraorbital ridge whereas the female presents with a much smoother appearance (Buikstra and Ubelaker, 1994; Krogman and İşcan, 1986; Walsh-Haney et al., 1999). Although sexual dimorphism in the forehead shape, frontal eminences, and supraorbital ridge is the result of the same growth process, Rogers (2005) found that the supraorbital ridge was both the easiest to assess for determining sex, as well as the most accurate. The forehead shape and frontal eminences provided individual accuracies of 44.5% and 31.9% respectively, and each misclassified over 30% of cases. The supraorbital ridge, however, achieved a significantly higher accuracy of 60.9% for assessing sex, and misclassified only 4.3% of cases (Rogers, 2005).

Sexual dimorphism in the shape of the supraorbital margin was first described by Broca (1875 in Graw et al., 1999) and is found along the upper margin of the eye orbits. This trait has generally been described as thick and protruding with rounded and smooth edges in males whereas, in females it is thin and sharper edged (Acsádi and Nemeskeri, 1970; Bass, 1995; Buikstra and Ubelaker, 1994; Walsh-Haney et al., 1999; White and Folkens, 2005). It is evaluated by palpating the upper edges of the orbits to determine thickness and shape (Buikstra and Ubelaker, 1994). In an investigation of 108 skulls from modern humans (67 males and 41 females) derived from Germany, Graw and colleagues (1999) tested whether or not the supraorbital margin could reliably determine sex from the skull. Rather than simply using palpation to assess thickness and sharpness, the authors used plasticine impressions to examine sex differences in the contours and angles of the margin. Two independent observers then classified the plasticine impressions on a seven-grade scale. The identification of sex differed between the two observers in only 3.4% of the impressions examined, and the accuracy of determining sex using this method alone was found to be approximately 70%.

Several researchers have claimed that if the mandible is included in the process of the identification of sex from the skull, accuracy increases from about 80% (cranium only) to 90% (cranium plus mandible) (Mays and Cox, 2000; St. Hoyme and İşcan, 1989). Studies of the mandible have revealed a number of sexually dimorphic features that are useful for assessing sex using this skeletal element (Eckel et al., 1994; Loth and Henneberg, 1996; Maat et al., 1997). In general, the male mandible tends to have more prominent muscle markings, greater height in the body, a broader ascending ramus, a robust lower border, a less obtuse angle formed between the mandibular body and ramus, and a more prominent chin (Scheuer, 2002; Walsh-Haney et al., 1999). This characteristic male mandible is the result of the continued growth of the alveolus and the expansion of the masticatory muscles in males, making the ramus progress to a more upright position during the adolescent growth spurt (Enlow, 1982).

One of the five aforementioned, traditionally recommended features used for sexing the skull is the mental eminence, or chin form, which is located on the mandible (Buikstra and Ubelaker, 1994; Byers, 2005; White and Folkens, 2005). The mental eminence is an anterior protrusion of the mandible in the chin region that can best be observed by holding the mandible by the chin between both thumbs and index fingers (Buikstra and Ubelaker, 1994; Byers, 2005). In females the chin does not generally protrude from the mandible and is rounded or pointed; in males, the chin is more prominent, usually projecting above the surrounding bone with a tendency toward a more square shape (Buikstra and Ubelaker, 1994; Krogman and İşcan, 1986; Wienker, 1984;). When used as an individual determinant of sex, Rogers (2005) found that chin form could correctly identify sex in just over half (56.3%) of the crania from the 19th century cemetery sample.

Sex differences in the shape of the mastoid process and the importance of these differences to the determination of sex have been described in detail by Hoshi (1962). This trait has also been emphasized by Acsadi and Nemeskeri (1970), Buikstra and Ubelaker (1994), White and Folkens (2005), and numerous others as one of the traditionally observed features of cranial morphology in assessments of sex from the skull

(Bass, 1995; Byers, 2005; Demoulin, 1972; Krogman and İşcan, 1986). Buikstra and Ubelaker (1994) score the mastoid process by comparing its size in volume and length with that of surrounding structures including the external auditory meatus and the zygomatic process of the temporal bone. A very small mastoid process which projects only a small distance below the inferior margin of the external acoustic meatus characterizes the female expression of the trait. Alternatively, a mastoid process that visibly projects beyond the inferior margin of the acoustic meatus in length, and is medium to large in volume typifies the male expression (Buikstra and Ubelaker, 1994; Byers, 2005; Walsh-Haney et al., 1999). An examination of the accuracy of the visual method for assessing sex using this particular cranial feature revealed an incorrect classification of sex in 6.4% of cases and a success rate of only 44.7% (Rogers, 2005), suggesting that the morphology of the mastoid process is not reliable for assessing sex.

Broca (1875) was the first to describe the differences between the sexes in the nuchal area of the occipital bone (Bass, 1995; Buikstra and Ubelaker, 1994; Byers, 2005; Nafte, 2000; White and Folkens, 2005). This is the location in which the neck muscles attach to the back of the skull, with observable markings being dependent upon the strength of the neck musculature (Bass, 1995; Byers, 2005; Keen, 1950). As a result of the longer duration of growth and muscular development in males, these muscle attachments produce a rugged appearance with a prominent bony crest (nuchal crest), in addition to more pronounced protuberances on the occipital bone (occipital protuberance); the female skull generally retains its gracile form, has a smooth nuchal area, and does not protrude (Rogers, 2005). Very few studies in the literature have evaluated the nuchal crest and/or the occipital protuberances as individual morphological criterion for accurately predicting sex (Gülekon and Targut, 2003). In an evaluation of the reliability of cranial morphology for determining sex, Rogers (2005) reported that sex could be assessed correctly in 53.3% of cases. According to Novotný et al. (1993), these results indicate that the nuchal crest is a trait of low reliability when examined as an individual bony element.

In a study done by Gülekon and Targut (2003), the usefulness of the external occipital protuberance was examined for the purposes of identifying useful criteria for assessing sex in cases of skeletal fragmentation. Modifying the previous morphological method developed by Broca (1875), who described six sexually dimorphic expressions of this cranial trait, the authors described three types, or morphological configurations, of the occipital protuberance which they felt appropriately demonstrated sexual dimorphism. These three protuberance types were investigated using the lateral cranium radiographs of 1000 individuals (500 males, 500 females) and 694 dry skulls (371 males, 323 females) from a 16th century Anatolian population. A smooth, non-protruding nuchal area was classified as Type 1, the presence of a crest characterized Type 2, and Type 3 involved the presence of a large extended spine that protrudes from the nuchal area. In the radiographic investigation, the occurrence of the smooth Type 1 was found in 85.4% of females and 17.8% in males. Type 3, the spine, type, occurred in 63.4% of males and 4.2% of females. Examinations of the dry skulls revealed that the incidence of Type 1 was found in 67.5% of females, and Type 3 was found in 55.2% of males. For both the radiographic and dry skull samples the incidence of Type 2, the crest type, was found to occur relatively equally between the sexes and it was concluded that this type is not as valuable for sex determination as Types 1 and 3. The findings from this study indicate that lateral cranium radiographs can be helpful in determining sex from the morphological features of the skull, and that this particular cranial trait, the external occipital protuberance, is a useful individual indicator of sex when skeletal remains are damaged or highly fragmentary.

In addition to the long list of sexually dimorphic morphological characteristics, other researchers have also employed the use of metric methods for determining sex from the skull (Demoulin, 1972; Giles and Elliot, 1963; Giles, 1970; Keen, 1950). In 1950, Keen used 100 skulls (50 male, 50 female) of South African origin to set up a series of cranial traits and dimensions that could be used for sexing adult crania. Combining both morphological and metric methods, Keen (1950) chose three basic morphological traits and four cranial measurements as being important features for sexual identification based on the earlier literature published by Hrdlička (1920) and Martin (1928 in Keen, 1950). The selected morphological traits included the supraorbital ridge, muscle markings on the occipital bone, and the anatomical structure of the external auditory meatus. The four metric measurements that were chosen included maximum cranial length, facial breadth, depth of the infratemporal fossa, and length of the mastoid processes. Using this combination of methods, Keen (1950) claimed that this series of cranial traits could sex skulls with an overall accuracy of 85%.

As was illustrated by Rogers (2005) with morphological methods, and Keen (1950) with a combination of both morphological and metric techniques, the determination of sex is highly reliable when the complete skeleton is available for analysis, and multiple features can be observed and measured (Krogman and İşcan, 1986; Rogers, 2005; Uysal et al., 2005). Although accuracy can be improved when multiple indicators are used, it is important that continued research be done on the accuracy of determining sex using individual cranial traits, and combinations of sexually dimorphic traits that can be found on a single bony element. This is because in archaeological situations, as well as in some forensic contexts, the skull, as well as much of the remaining skeleton, is often incomplete, and/or in a fragmentary state, making it more difficult to assess sex since not all of the sexually dimorphic elements of the skull are available for observation. Many metric techniques are applicable only when the complete skull is available, rendering a number of normally very reliable methods ineffective (Holland, 1986). As a result, an increasing amount of literature has been published on the development of reliable metric sex determination techniques using fragmentary crania (Akansel et al., 2008; Catalina-Herrera, 1987; Günay and Altinkök, 2000; Holland, 1986, 1989; Lynnerup et al., 2006; Norén et al., 2005; Uysal et al., 2005; Wahl and Graw, 2001).

The observation that the cranial base exhibits marked structural differences between the sexes (Martin, 1928 in Keen, 1950) has attracted attention from several researchers as this area of the skull tends to survive fragmentation well (Catalina-Herrera, 1987; Graw et al., 2005; Holland, 1986, 1989; Lynnerup et al., 2006; Uysal et al., 2005). High survivability rates and overall good preservation have given the structural elements of the cranial base a high diagnostic value for the identification of sex in fragmentary skeletal remains (Graw et al., 2005).

The cranial base, along with the brain case, follows an early pattern of growth in which 90% of adult size is reached prior to the 12th year of life. The earliest growing parts of the skull are the brain case and the area around the foramen magnum as they follow the early growth pattern of the brain and spinal cord. The growth of skeletal structures in the area of the foramen magnum are complete at about 6 years, and the four parts of the occipital bone are joined and fused around the same time resulting in the complete bony enclosure of the foramen magnum (Enlow, 1982; Humphrey, 1998). Schultz (1962 in Humphrey, 1998; Rogers, 2005) suggested that the earlier growing parts of the skeleton are commonly less sexually dimorphic than elements that complete growth later during the adolescent period. However, significant levels of sexual dimorphism can also be found in skeletal elements that complete growth prior to adolescence, including the elements that form the cranial base (Humphrey, 1998; Rogers, 2005).

Sex determination of fragmentary skulls through the metric analysis of the cranial base has been explored in a number of various research projects (Catalina-Herrera, 1987; Graw et al., 2005; Holland, 1986, 1989; Lynnerup et al., 2006; Teixeira, 1981; Wahl and Graw, 2001). For example, Holland (1986) defined nine measurements that could be taken from both the foramen magnum and the occipital condyles. This technique proved to be effective for determining sex with a reported accuracy of 70-90% (Holland, 1986). Holland's (1986, 1989) research illustrated that the cranial base is useful for determining sex in both archaeological and forensic contexts when the skull is fragmentary or poorly preserved; however, it is suggested that the technique be used with appropriate caution until the time that it is tested on a more geographically diverse population.

Additional studies of the cranial base that are worth noting include Catalina-Herrera's (1987) metric study of the foramen magnum and Teixeira's (1981) earlier work involving the surface area of the opening of the foramen magnum. Catalina-Herrera

(1987) reported that the difference in the sagittal and transverse diameters, as well as the total area, of the foramen magnum between males and females were statistically significant when taking metric values from a Spanish anatomical sample of 100 adult skulls (74 male, 26 female). In a smaller sample of 40 (20 males, 20 females) Brazilian skulls, Teixeira (1981) indicated that if the surface area of the foramen magnum is $963mm^2$ or larger the remains belong to a male, and if the surface area is $805mm^2$ or less the remains are female.

Published methods for metrically sexing fragmentary skulls have established that the overall structure of the cranial base exhibits a degree of sexual dimorphism that allows for the development of reliable techniques for assessing sex (Catalina-Herrera, 1987; Holland, 1986, 1989; Uysal et al., 2005). Since the metric features of the cranial base are considerably different in males and females, it has been suggested that the petrous portion could be of value for assessing sex in fragmentary crania (Akansel et al., 2008; Graw et al., 2005; Lynnerup et al., 2006; Norén et al., 2005; Wahl and Graw, 2001).

Due to its protected location at the cranial base, and its extremely dense and robust structure, the petrous portion of the temporal bone is frequently found intact and well preserved in cases of extreme fragmentation. In fact, it has been established that the petrous portion is one of the hardest bones in the body (Rarey, 1985) and is often found even after the burning or cremation of human remains (Lynnerup et al., 2006; Schutkowski, 1983; Wahl and Graw, 2001). Therefore, it has been of interest to several researchers to develop reliable methods for determining sex using this skeletal element. The use of the petrous portion of the temporal bone as a diagnostic tool for sex determination has been discussed in the recent forensic and anthropological literature and has been demonstrated to reliably predict the sex of skeletal remains (Akansel et al., 2008; Graw et al., 2005; Kalmey and Rathbun, 1996; Lynnerup et al., 2006; Norén et al., 2005; Papangelou, 1975; Wahl and Graw, 2001).

The internal auditory canal (meatus acusticus internus) has been considered an important part of the temporal bone for determining sex in several studies (Akansel et al., 2008; Lynnerup et al., 2006; Norén et al., 2005; Papangelou, 1975). Early claims that the petrous portion of the temporal bone was an unsuitable skeletal element for differentiating sex (Schaefer, 1961 in Wahl et al., 2001) were disputed in a volumetric study of the internal auditory canal performed by Papangelou (1972). The author found that the canal was larger in volume in adult females than in males. In a later follow-up study, the author analyzed the shape and dimensions of the same canal for sex differences and found that the lengths of the anterior and posterior walls, as well as the horizontal diameter were longer in males (Papangelou, 1975).

The pars petrosa ossis temporalis, or the petrous portion of the temporal bone is, essentially, a three-sided pyramid that can be found on both sides of the skull between the middle and posterior fossae, and its shape and structure give the cranial base its characteristic contours (Howard et al., 1990; Wahl and Graw, 2001). The base of the petrous pyramid forms the lateral extracranial surface of the temporal bone, and the three sides correspond to the inferior extracranial surface of the skull base, and the anterior and posterior intracranial surfaces (Howard et al., 1990). The internal acoustic canal is a short canal that can be found on the medial aspect of the posterior intracranial surface, also referred to as the facies posterior or posterior face, and is oriented nearly perpendicular to the midsagittal plane (Howard et al., 1990; Papangelou, 1972). The internal acoustic canal begins with an oval opening on the posterior face and extends laterally into the petrous bone. It contains the internal auditory artery and vein, and three cranial nerves: the facial, the intermediate, and the vestibulocochlear, also known as the auditory nerve (Papangelou, 1972).

As a result of the reported sex differences in the petrous bone, Wahl (1981, in Norén et al., 2005) suggested that the most proximal part of the internal auditory canal, the meatus or opening, exhibited sexual dimorphism in the angle at which the canal opened up to the surface of the bone. Wahl (1981 in Norén et al., 2005) defined this angle as the lateral angle. The lateral angle method, primarily developed by Wahl (1981 in Norén et al., 2005) in this early study, has recently received increasing international interest through the research of Akansel et al. (2008), Graw et al. (2005), and Norén et al. (2005). This method involves taking measurements of the angle by filling the internal acoustic canal with clay (Wahl, 1981 in Norén et al., 2005) and, in more recent studies, silicone-based casting materials (Graw et al., 2005; Norén et al., 2005) to produce a negative cast of the canal. These casts are then used to take measurements of the acute angle that is formed by the relation of the lateral wall of the internal acoustic meatus to the posterior face of the petrous bone which surrounds the opening (Graw et al., 2005; Norén et al. 2005; Wahl 1981).

Norén et al. (2005) evaluated the reliability of the lateral angle method of the internal auditory canal for estimating sex using two samples. The petrous bones of 113 individuals (120 right and left pairs from 60 individuals and 53 from the left side only) of known sex were removed at autopsy, and subsequently macerated. This modern forensic sample originated from the Institute of Forensic Medicine at the University of Tübingen, Germany. The second sample was derived from a compilation of two archaeological samples from Scandanavia and consisted of 60 petrous bones from 60 individuals (an unpaired collection consisting of both left and right sides). Traditional methods of sex determination using pelvic morphology were used to assess the sex of the 60 (34 males, 26 females) adult individuals from the archaeological sample. The complete skull was available for 59 of the 60 individuals and, thus, in a separate trial sex was assessed using conventional morphological methods of the cranium (39 males, 20 females); pelvic and cranial sex determinations were carried out independently.

In concordance with earlier studies published in the German literature (Albrecht, 1997; Graw, 2001), the authors found that a sectioning point of 45° provided the best discrimination between the sexes, with females having an angle size greater than, or equal to 45°, while the angle size in males was less than 45°. A higher accuracy could not be achieved by analyzing pairs of petrous bones as the relationship between the left and right angles were close enough that they did not influence sex determination. In blind trials using the forensic sample of known sex, the lateral angle method correctly assigned sex in 83.2% of petrous bones. In the archaeological sample, true sex was not known; however, results from the lateral angle method were directly compared first to sex determined from the pelvis and, in a second trial, to sex determined from the skull. Results from the archaeological sample indicated that the agreement between sex determined from the lateral angle and pelvic sex was 86.67%; this is slightly higher than the agreement between sex as determined by cranial morphology (78.33%). Since it is generally acknowledged that the pelvis is one of the most reliable and important structures of the human skeleton for the determination of sex, and since it was found that the lateral angle size showed the best concordance with pelvic morphology, it has been suggested that perhaps the lateral angle and, therefore, the sexual dimorphism of the petrous portion, is not simply the result of differences in cranial size, but is related to genetically controlled sex differences in the architecture and shape of the skull that occur early during the growth process of the cranial base (Norén et al., 2005).

A similar study done by Graw et al. (2005) examined 410 modern forensic petrous portions of known sex for the purpose of analyzing sex differences between the lateral angle as well as the medial angle of the internal acoustic canal. Results from this study revealed that the lateral angle was, on average, 10° smaller in males than in females and that the medial angle was approximately 5° smaller in females than in males.

According to the findings from this research, the lateral angle had a greater diagnostic value than the medial angle; however, the accuracy of the lateral angle to determine sex was significantly lower than the study published by Norén et al. (2005), and correctly determined sex in 66% of the observed specimens (Graw et al., 2005). Nonetheless, Graw et al. (2005) concluded that the measurable differences in the lateral angle of the petrous portion allow for a reliable determination of sex even on fragmentary or partially preserved skulls. This is in concordance with the standards set by Novotný et al. (1993) in which sexually dimorphic traits of the skeleton must correspond with actual sex in more than 60% of cases to be considered very reliable.

In addition to the sex differences of the lateral angle, Graw et al. (2005) and Graw (1999) have suggested that the internal opening of the auditory canal also displays a degree of sexual dimorphism. In a response to the previously published literature on the sex differences of the internal auditory canal, Lynnerup et al. (2006) tested the diameter of the internal opening to assess the reliability of this trait for determining the sex of skeletal remains. This technique was developed in response to the high degree of precision needed for, and time consuming nature of the lateral angle method. Rather than casting the inner structure of the canal, this simple method involved measuring the diameter of the medial opening of the internal acoustic canal using a collection of ordinary drills. The method was tested on a forensic sample of 113 left petrous bones of known sex, and results demonstrated that sexual dimorphism in diameter size was statistically significant and that correct sex could be assigned with an accuracy of 70% (Lynnerup et al. 2006). The authors have stated that although the diameter of the internal opening is methodologically reliable, it should only be used in concordance with other, more reliable sex indicators when and if they are available for observation.

In conclusion, although not as accurate as pelvic sex determination, the accuracy of determining sex from the skull ranges from approximately 80-90%, suggesting that the skull is also a reliable skeletal structure for sexing human skeletal remains (Giles and Elliot, 1963; Keen, 1959; Mays and Cox, 2000;).

Other Postcranial Elements

Although the pelvis and the skull provide the most numerous and accurate indicators of sex, a number of aspects on the remainder of the postcranial skeleton are also sexually dimorphic to varying degrees (Scheuer, 2002; Wienker, 1984). These sex differences are generally a reflection of the larger size and muscular robusticity of the male and are especially observed in overall joint size (Scheuer, 2002). In most of these postcranial elements, however, the overlap between males and females is considerable, and sex differences are especially difficult to assess in the remains of individuals who have not yet reached puberty (White and Folkens, 2005). As a result, researchers began developing different approaches using either single dimensions or several measurements taken from selected postcranial elements (Bass, 1995; Byers, 2005; Stewart, 1979; Trotter and Gleser, 1952). Several studies have demonstrated that these approaches are both accurate and reliable for sexing the postcranial skeleton (Byers, 2005; Cöloğlu et al., 1998; İşcan et al., 1985, 1998; Mall et al., 2000; Trancho et al., 1997).

Trotter and Gleser (1952 in Byers, 2005) studied the value of long limb bone lengths for the purpose of determining living stature, assessing differences between ancestral groups, and identifying sex. Although intermediate values overlapped between the sexes, the sex of bones whose measurements lay at the lowest and highest of the extremes could be distinguished (Trotter and Gleser, 1952 in Byers, 2005). Since then, nearly all of the long bones, foot bones, hand bones, vertebrae, and sternal rib ends have been measured and statistically analyzed in studies assessing the sexual dimorphism of the human skeleton (Byers, 2005; Scheuer, 2002).

In early studies of sex differences that could be measured from the joint surfaces of the postcranial skeleton, Dwight (1905) focused on the humerus and its joint surface with the glenoid cavity of the scapula. In a validation study of Dwight's (1905) research, Stewart (1979) reported that his results were comparable to those published by Dwight (1905), with head diameter values below 43mm being almost certainly female and measurements above 47mm being most certainly male. Measurements of 43-44mm could be classified as probable female, while those measurements from 46-47mm are probable male. Those values that fell in between represented the male-female overlap and were indeterminate values for assigning sex. In addition to humeral head diameter, Stewart (1979) also tested Dwight's (1894 in Stewart, 1979) claim that the point of articulation of the scapula with the humerus also displayed differences between the sexes. As a result of this research, Stewart (1979) suggested that two features of the scapula are in fact useful indicators for the assessment of sex. The first feature is the maximum length between the superior and inferior borders, which was found to be less than 14cm in females, while lengths exceeding 17cm indicated male. The second feature, length of the glenoid cavity, was reported as being generally larger in males, as a result of the larger humeral head diameter, with measurements exceeding 36mm, while those below this value were found to generally belong to females (Stewart, 1979).

In a later publication focused on human osteology, Bass (1995) detailed several projects on the sexual dimorphism of the humerus such as those done by Thieme (1957) on the humeral length and epicondylar width; France (1985 in Bass, 1995), who continues to refine measurements and statistical approaches of the humerus; and Dittrick and Suchey (1986), who reported that a single measurement taken from the transverse diameter of the humeral head could accurately determine sex in 88-96% of cases.

According to Bass (1995) and İşcan (2005), the femur has probably been one of the most studied postcranial elements of the human skeleton, especially for its value in determining sex. Sexual dimorphism in this particular bone has been studied extensively for many different populations across the globe (Liu, 1989; MacLaughlin and Bruce, 1985; Mall et al., 2000; Purkait, 2005; Steyn and İşcan, 1997). In a study of a contemporary German population, Mall et al. (2000) took measurements from six femoral dimensions (maximum length, maximum mid-shaft diameter, condylar width, vertical head diameter, head circumference, transverse head diameter) for the purpose of analyzing the degree of sexual dimorphism in the femur. These measurements were taken from 170 femora (100 male, 70 female) and results revealed accuracies ranging from 67.7-89.6% when each dimension was considered on its own, with the transverse diameter being the best individual indicator of sex. When the measurements taken from the mid-shaft diameter and head circumference were combined, sex could be correctly classified in 91.7% of cases (Mall et al., 2000). Several other examples of the use of the femur which are worth mention include Liu's (1989) study of 17 femoral dimensions and concluded that femoral head diameter was the most reliable dimension for determining sex with an accuracy of approximately 85%. Seidemann et al. (1998) examined the supero-inferior femoral neck diameter for sex differences in a sample consisting of a combination of African-American and Caucasian femora and also achieved excellent results for sexing with an accuracy rate ranging from 87-92%.

Although the humerus and femur appear to be the most studied elements for sex determination in the postcranial bones, the literature is not restricted to the larger long bones, but also includes research on elements such as the tibia (Holland, 1991; Trotter and Gleser, 1958; İşcan et al., 1994), the radius (Allen et al., 1987), the patella (Introna et al., 1998), hand bones (Smith, 1996), foot bones (Smith, 1997), the scapula (Dwight, 1894; Stewart, 1979), the ribs (Cöloğlu et al., 1998; İşcan, 1985), and the vertebral column (MacLaughlin and Oldale, 1992). White and Folkens (2005) have summarized from the literature that results from single measurements, or combinations thereof, have been found to accurately assess the sex of skeletal remains in approximately 80-90% of cases when using the most dimorphic postcranial elements (Albanese, 2003; Byers, 2005; Konigsberg and Hens, 1998; Pons, 1955 in Wienker, 1984; Saunders and Hoppa, 1997; Torwalt and Hoppa, 2005).

Statistical Approaches

Various statistical approaches such as discriminant function analysis and regression analysis have been proposed that have yielded reliable results for determining sex in human skeletal remains (Albanese, 2003; Byers, 2005; Konigsberg and Hens, 1998; Pons, 1955 in Wienker, 1984; Saunders and Hoppa, 1997; Torwalt and Hoppa, 2005). Many of these studies have been able to correctly identify sex in at least 80% of cases, and others have offered accuracies greater than 90% (Falsetti, 1995; Purkait, 2001; Robling and Ubelaker, 1997; Rogers, 1999).

In general, the anthropologist will utilize these statistical approaches for two different purposes when studying the sexual dimorphism of the skeleton. The first is to evaluate the levels of sexual dimorphism within and between populations and the second is to assign group membership (male or female) to an unknown specimen (Albanese, 2003; Saunders and Hoppa, 1997; Torwalt and Hoppa, 2005). These two purposes have been referred to as discrimination and allocation, respectively, with each utilizing a different statistical approach (Saunders and Hoppa, 1997; Albanese, 2003).

Discriminant function analysis is a method that is used for the purpose of distinguishing between two or more groups, or distinct categories, based on any number of anthropometric measurements (Albanese, 2003; Byers, 2005). One of the more basic analyses is linear discriminant analysis, where a simple regression equation is used to predict the value of a dependent variable using a single independent variable. On the other hand, multiple regression analysis can be thought of as an expansion of simple linear regression and is applied when a dependent variable, such as sex, can be predicted by two or more independent variables (Giles, 1970; Giles, 1963). Multiple regression analysis appears to be the most commonly used statistical method in the sex determination literature.

Since the 1950's, researchers have been developing a series of published standards of discriminant functions for sexing, which have been calculated from known sex samples for various populations, and using a variety of osteological measurements on both the cranial and postcranial skeleton (Calcagno, 1980; Giles, 1964; Giles, 1970; Giles and Elliot, 1963; Graw, 1999; Hanihara, 1958; Thieme, 1957; among many). Many of these early standards were compiled and organized by Giles (1970), based on population origin, into functions that are applicable to the cranium, mandible, cranium and mandible, the postcranial skeleton, and the complete skeleton. A detailed examination of the theory and methods behind the generation of the mathematical formulae and weighted coefficients used in discriminant function analysis is beyond the scope of the present study; however, for a more detailed discussion see Kendall (1957), Giles (1970), and Giles and Elliot (1963). Since the discriminant functions are provided through previously published standards, applying the function to a specimen of unknown sex is a relatively straightforward process. A set of predetermined osteological measurements is taken from the skeletal remains and are entered into the appropriate discriminant function. The products of these calculations are then summed to get a final numerical value, known as the discriminant function score (Giles, 1970; Wienker, 1984). This number is then compared with the sectioning point provided for the particular function used, which is the midpoint value calculated from the mean score for males and the mean score for females from the original known sex population. Those values that fall on the male side of the predetermined sectioning point are assessed as male, while those on the female side of the sectioning point are considered to be female (Byers, 2005; Giles, 1979; Giles and Elliot, 1963; Wienker, 1984). To summarize this discussion in more simple terms, discriminant function analysis is used to determine whether males and females differ with regard to the mean values of the independent variables; in this case, a series of osteological measurements. If so, those same variables can then be used to assess the sex of unknown skeletal specimens.

One of the most well known publications on discriminant function sexing is the method of Giles and Elliot (1963), who used a total of 408 skulls from the Terry and Todd Collections to assess sex using a series of cranial measurements. Both whites and blacks were included in the sample (108 white males, 79 white females, 113 black males, 108 black females), and nine measurements were chosen based on the ease of taking the measurement and the potential for sex discrimination. For the statistical analyses, 75 specimens from each of the population and sex categories were chosen to calculate the discriminate functions, and the rest were set aside as a check sample. From various combinations of the nine cranial measurements a total of 21 discriminant functions were derived to discriminate sex in three population sets: whites, blacks, and whites plus blacks. The authors demonstrated that sex could be correctly predicted with an accuracy of 82-89% when measurements taken from the check sample were entered into the corresponding discriminant functions and their resultant scores were compared with the predetermined sectioning points.

Although the method developed by Giles and Elliot (1963) can be considered a very reliable technique, according to the standards suggested by Graw (1999), Holland (1986), and Novotný et al. (1993), a problem arises with this particular method when presented with a skull that is in a fragmentary condition. All 21 discriminant functions developed by Giles and Elliot (1963) for sexing the skull require measurements of the bizygomatic diameter, 18 functions have need of the glabello-occipital length, and 15 require the maximum width of the skull. These measurements can be difficult, if not impossible, to obtain from fragmentary crania (Holland, 1986). The base of the skull, however, remains intact in many cases of skeletal fragmentation and, as has been discussed previously, exhibits sexually dimorphic characteristics. Several researchers have used a number of combinations of various measurements to sex the cranial base using discriminant function analysis (Graw, 1999; Holland, 1986; Kalmey and Rathbun, 1996; Wahl and Graw, 2001). Graw (1999) used six sexually dimorphic dimensions of the cranial base in order to develop three discriminant functions from 228 forensically modern skulls from south-western Germany, and was successful in correctly assigning sex in nearly 80% of cases.

Smaller elements of the cranial base, such as the previously mentioned petrous portion of the temporal bone have also been studied using statistical approaches. Kalmey and Rathbun (1996) analyzed nine dimensions on both the left and right petrous portions by discriminant function analysis to determine which combination of measurements offered the best discriminating power to determine sex. The sample used in this study came from the Terry collection and consisted of the skulls of 138 individuals of varying ancestries. The dimensions of the petrous portion were chosen based on the ease of identifying landmarks, and the survivability of those landmarks in fragmentary circumstances. In order to properly and accurately measure these dimensions, the skulls were sectioned both sagittally and transversely. Statistical evaluations were carried out on the nine measurements and four were found not to be statistically different between the sexes; therefore, only five of the original nine measurements were used to calculate the discriminant functions. No statistically significant ancestral differences were reported for the five measurements used to determine sex. Thus, Kalmey and Rathbun (1996) suggest that the functions developed in this study can be applied without prior knowledge of ancestry. The results reported by the authors indicated that when the functions were applied to an outgroup test sample of 18 individuals, also from the Terry Collection, accuracies up to 83% could be achieved. In a cross-validation, in which each individual is tested by a discriminant function created by all of the data except that individual, accuracies in determining sex from the petrous portion ranged from 66-74%.

Continued testing of the metric sex differences of the petrous bone using more modern skeletal material has been completed by Wahl and Graw (2001), who also considered the effects of age-related changes and side differences in the cranial base on the sexual dimorphism of the petrous portion. When all of these factors were considered, the maximum accuracy of sex determination by discriminant function analysis, based on 10 measurements from 410 modern forensic petrous portions, is similar to the accuracy achieved by Kalmey and Rathbun (1996) and allows correct classification in 66% of cases. Although the techniques for sexing fragmentary crania presented here are less accurate than Giles and Elliot's (1963) discriminant function analysis of the complete cranium, these alternative methods may prove more useful in cases of severe fragmentation or cremation when other cranial and postcranial elements are unavailable (Holland, 1986; Wahl and Graw, 2001).

In summarizing the discriminant function sexing of human skeletal remains, it is important to discuss the pros and cons of using such an approach, which have been discussed in detail in the literature (e.g. Albanese, 2003; Calcagno, 1981; Giles, 1970; Saunders and Hoppa, 1997; Torwalt and Hoppa, 2005; Wienker, 1984). Firstly, when dealing with samples of reasonable size, discriminant function analyses can have similar accuracies in sexing as the visual approaches, but are considered to be much more objective (Calcagno, 1981; Giles, 1970). Each discriminant function formula has its own reliability, and many of them accurately assess the sex of the skeleton in at least 80% of cases on average (Giles, 1970; Giles and Elliot, 1963; Luo, 1995; Patil and Mody, 2005; Steyn and İşcan, 1998; Uysal et al., 2005; Wienker, 1984). Another advantage to using this type of statistical approach lies in its ease of use; it is possible for non-experts and individuals with little osteological experience to objectively establish the sex of a specimen by taking the prescribed measurements and relating the mathematical scores to a published standard series. This is of particular importance for providing initial identifications in cases of mass disasters when and if the appropriate experts are unavailable or in short supply (Giles, 1970).

Although discriminant function analyses have proven to be both accurate and objective, there are several problems inherent in the technique, especially as it pertains to population specificity with published standard functions (Calcagno, 1981; Giles, 1979;

Walsh-Haney et al., 1999; Wienker, 1984). As with many of the metric and statistical approaches, the formulae are applicable, in theory, only to material that is derived from the same population from which the formulae were originally developed. This has created controversy among anthropologists as to the use and effectiveness of this technique (Calcagno, 1981). This alleged population specificity was critically evaluated in a comprehensive study done by Calcagno (1981), who examined the overall applicability of discriminant function analysis as a sexing technique using the mandible. In this study Calcagno (1981) concluded that discriminant functions rely heavily on overall skeletal size, which can vary significantly between populations. Therefore, the applicability of discriminant function analysis is dependent upon both the degree of sexual dimorphism within populations, as well as size variations for each sex between populations (Calcagno, 1981; Thieme and Schull, 1957).

In conclusion, the use of discriminant function analysis as a means of determining sex of an unknown individual should be used with the necessary caution, and only as a secondary, or corroborative, means of assessing sex when used with unrelated populations (Calcagno, 1981).

Discriminant function analysis is regularly encountered in the sex determination literature; however, it is now more often being replaced with logistic regression; a method which is more statistically robust, easier to use and understand, and requires fewer theoretical assumptions (Albanese, 2003). For example, unlike discriminant function analysis, logistic regression makes no assumptions about the distribution of the independent variables such that these variables do not have to be normally distributed or linearly related in order to apply this statistical method (Norusis, 1990 in Albanese, 2003). In statistics, logistic regression is a model used to predict the probability of occurrence of an event by fitting data to a logistic curve, or the so-called S-curve (Torwalt and Hoppa, 2005). In other words, the probability of group membership for the dependent variable can be predicted from knowledge of the values of one or more independent, or predictor, variables. This type of statistical model can also provide information on the strength of the relationships between the chosen independent variables, and their suitability for predicting the outcome of a dependent variable such as sex (Saunders and Hoppa, 1997).

Logistic regression methods are well suited for sex determination research as the probability of an individual being male or female - as opposed to strictly discriminating between these two groups through the calculation of a precise numerical value - can be estimated from a single, or set of independent variables that are known to adequately predict sex (Saunders and Hoppa, 1997; Torwalt and Hoppa, 2005). In comparing the two statistical methods discussed here, discriminant function analysis is specifically performed to discriminate between males and females, whereas logistic regression is employed to allocate individual specimens to either sex. Saunders and Hoppa (1997) and Albanese (2003) have suggested that logistic regression equations are more appropriate for the prediction of sex than the more commonly employed statistical method of discriminant function analysis.

In examining the different aspects of discrimination and allocation, Campbell (1984) also advocates the use of probabilistic statistical techniques such as logistic regression. He suggested that the ability to allocate an individual to a specific group had very little in common with the ability to discriminate between groups and, thus, these two concepts should not be confused, nor should they be considered as similar techniques (Campbell, 1984). For example, in a 1992 study on sex allocation by analysis of the tibia, Kieser et al. (1992) explicitly stated that although sex discrimination has proven useful in populational studies, it has little or no value in research, specifically in forensic contexts, which seeks to allocate a given skeletal specimen to either sex. Whereas the forensic anthropologist most commonly uses the metric dimensions of the skeleton to allocate sex to an individual specimen, these same metric dimensions are also used by the anthropologist to assess sex related variability within and between past populations (Campbell, 1984; Saunders and Hoppa, 1997). Therefore, although both discriminant function analysis and logistic regression have been successfully used in sex determination research, it is important that one chooses the statistical method which is most fitting to the research questions being asked.

Logistic regression models are developed using osteological measurements taken from a skeletal sample of known sex which is subsequently separated into two sub-samples- the model sample and the test, or holdout, sample (Albanese, 2003). The logistic regression models are then derived from the model sample, while the holdout sample is excluded from this mathematical process (Albanese, 2003; Saunders and Hoppa, 1997). Using the data collected from the model sample, models are formulated mathematically by relating the probability of some event (being male or female) occurring to the set of chosen measurements. These models can then classify the skeletal specimen into one of two groups (male or female) by indicating the probability that the specimen belongs to one of the groups based on the collected metric attributes (Press and

Wilson, 1978). The purpose of the holdout sample is to then test the accuracy of the subsequently developed models against documented sex.

In order for logistic regression models to be useful, the overall accuracy achieved should be at least 85% with little bias in accuracy between males and females, and the measurements chosen should be minimally affected by population differences (Albanese, 2003; Saunders and Hoppa, 1997). Thus, logistic regression equations, or probability functions, for sex determination are derived from skeletal metrics which have shown consistency in the replicability and stability of measurements, as well as a high degree of reliability in allocating sex to unknown specimens.

In a study done by Albanese (2003) a logistic regression method for determining sex was developed using measurements taken from the pelvis as well as the femur. The pelvis, specifically the pubis, and the femur, particularly the joint surfaces, were chosen for this study as both elements are highly sexually dimorphic, and the size of the pubis relative to the whole pelvis and the femur is highly effective in maximizing accuracy when determining sex (Albanese, 2003). Using samples derived from the Terry and Coimbra Collections (19^{th} and 20^{th} centuries), measurements of the superior pubis ramus length, along with further traditional measurements of the pelvis and femur were taken. A logistic regression sex determination method was then developed from these measurements and produced an allocation accuracy of 90-98.5%. In addition to a high allocation accuracy, results from this study also indicated that geographic origin and time period were irrelevant to the accuracy of the method.

In an earlier study done by Saunders and Hoppa (1997), logistic regression analysis was used to estimate probability functions for the sex allocation of unknown individuals using the nineteenth century St. Thomas' Church cemetery sample from southern Ontario, Canada. Logistic regression equations for sex determination were constructed from measurements of the major long bones to assess the accuracy of sex allocation using a wide variety of postcranial measurements, and to determine which measurements most reliably predicted sex, and which measurements remained stable regardless of shifts in the mean distribution of the sexes. The results of this study indicated that long bone lengths provided the lowest levels of correct sex allocation, whereas measures of the articular surfaces, followed by shaft measures provided a range of accuracy of sex allocation from 71-95% for each sex in both the analysis and the holdout samples. Measures of the joint surfaces showed little to no bias in predictability between males and females thus, Saunders and Hoppa (1997) suggest that these measures may be the most suitable for estimating sex when using the long bones.

In addition to the statistical research that has been discussed above, there are also those studies which utilize statistical approaches for the explicit purpose of testing the validity and accuracy of previously developed sex determination methods (Konigsberg and Hens, 1998; Torwalt and Hoppa, 2005; Uysal et al., 2005; Walker, 2008). For example, in a recent study done by Walker (2008) the accuracy of sex determination based on visual assessments of cranial traits, using the ordinal scoring system previously published by Buikstra and Ubelaker (1994), was tested using discriminant function analysis. The accuracy of visual assessments of sex using the mental eminence, supraorbital margin, glabellar region, nuchal crest, and mastoid process was examined using a modern known age and sex sample of 304 skulls from both the Terry and Hamann-Todd Collections, and an ancient Native American sample of 156 individuals whose sex was determined based on an assessment of pelvic morphology. The subsequent ordinal scores were then used to calculate sex determination discriminant functions which produced accuracies between 69% and 83% for the modern sample and 57% to 70% for the ancient Native American sample when using a univariate approach. On the other hand, the multivariate analysis correctly classified 89% of individuals when models that included all 5 cranial traits were used, 88% when three traits were used, and 84% with two. In an earlier, but similar, statistical study Konigsberg and Hens (1998) used the same five visual cranial traits as those examined in the more recent study completed by Walker (2008) to test their validity for determining sex when using logistic regression analysis. Logistic regression models were calculated based on the ordinal scores from 138 crania and correctly classified 89.19% of males and 71.88% of females for an overall correct classification of 81.16%.

In a validation study using logistic regression sex determination methods, Torwalt and Hoppa (2005) evaluated the determination of sex using radiographic features of the chest. The purpose of this research was to test the validity of a set of previously published measurements reported by McCormick et al. (1985) for determining skeletal sex from thoracic radiographs and their use in forensic contexts. Results from this validation study were consistent with the results reported in the previously published work of McCormick et al. (1985) and demonstrated that the accuracy for all of the univariate logistic regression models was consistently higher for males rather than females. However, Torwalt and Hoppa (2005) found that the issue of accuracy bias between males and females, when using the bones of the thoracic region, can be resolved when a multivariate model is used. In conclusion, in keeping with the earlier results reported by McCormick et al. (1985) and those results obtained through the validation study which employed logistic regression models, measurements of the thoracic region appear to be useful predictors of sex as a result of both the high degree of accuracy in results (90.3%-95.8%) as well as the ease of measurement reproducibility.

In summary, both discriminant function and logistic regression analysis provide reliable statistical means for determining sex; however as a result of its more robust nature, several researchers have recently advocated the use of logistic regression as a more appropriate means of assessing sex in anthropological research (Albanese, 2003; Saunders and Hoppa, 1997; Torwalt and Hoppa, 2005).

X-Ray Computed Tomography

The most common method by which anthropologists extract information such as sex from human remains is through the simple visual inspection of dry bones; however, with the emergence of computed tomography (CT) in the early 1970's (Metcalfe, 2008), and the subsequent successful applications of advanced medical imaging techniques to anthropological investigations, a new field of research has emerged: Virtual Anthropology (Recheis et al., 1999; Weber et al., 1998; Weber et al., 2001). Virtual Anthropology has been defined by Weber et al. (1998) as the three dimensional analysis of anthropological objects using digital data sets within a computer environment. It is a branch of innovative scientific investigation that combines traditional anthropological methods with radiology, advanced medical imaging, and computer science (Recheis et al., 1999; Weber et al., 1998; Weber et al., 2001).

Since the late 19^{th} century, radiology has been used to evaluate skeletal remains in many anthropological investigations (Braunstein et al., 1988) and, since 1974 computed tomography has also been an available medical technology (Metcalfe, 2008). However, it was not until the discovery of the Tyrolean Iceman in 1991 that this new era of computerized anthropological research gained rapid popularity (Recheis et al., 1999; Weber et al., 1998). The fragile and vulnerable state of the Iceman made physical examination difficult and extremely restrictive; therefore, researchers began seeking out alternative methods to investigate the remains in greater detail without causing any significant damage. The analysis of the Iceman using CT, three-dimensional volume rendered images, and sterolithographic models led to an increasing interest into the potential of medical imaging technology in other kinds of anthropological research (Recheis et al, 1999).

The acquisition of data within the field of Virtual Anthropology, involves using standard medical imaging techniques such as CT wherein a large series of x-rays are taken around a single axis of rotation to produce a number of individual, computer-based slices of the object being scanned (Metcalfe, 2008; Weber et al., 1998). These slices of data can then be combined using biomedical image processing software to create both two-dimensional visualizations and three-dimensional pictures, or reconstructions, of the desired object (Gardner et al., 2004; Marx and Auria, 1988; Metcalfe, 2008; Weber et al., 2001). Three-dimensional osteological reconstructions from CT data have recently been established as routine tools for analyzing both modern and ancient human skeletal remains and have opened up new insights and research possibilities for physical anthropology.

The precision and accuracy of two-dimensional and three-dimensional osteological reconstructions in anthropological research has been investigated by several authors (e.g. Aubin et al., 1997; Cavalcanti et al., 2004; Hildebolt and Vannier, 1988; Smith et al., 2002; Telmon et al., 2005; Uysal et al., 2005; Weber et al., 1998). For example, Weber et al. (1998) have posed several important questions regarding the accuracy of computer-based analysis: How well can anthropologists take linear and volume measurements on virtual objects on a computer screen? Can objects be handled and manipulated in a satisfying way in a computer environment? How accurate and reproducible are virtual measurements? In an attempt to answer these questions, Weber and colleagues (1998) CT scanned ten *Homo sapiens* skulls from the Weißbach collection using a modern medical CT. The subsequent raw data was processed to obtain three-dimensional reconstructions of each of the ten skulls. Linear and volume measurements were performed on the virtual skulls as well as directly on the dry skulls using traditional physical methods including spreading and sliding calipers, and water displacement. After an extensive comparison of the results, Weber et al. (1998) concluded that the linear and volume measurements taken from the virtual objects were comparable to those taken using the traditional methods, with a mean absolute difference of 0.58% ± 0.49 for the linear measurements, and 2.26% ± 0.86 for the volume measurements. It was also noted that the reproducibility of the virtual measurements was better than that of the traditional methods, indicating that virtual measurements are just as accurate and reproducible as physical measurements. Finally, the handling and manipulation of the virtual objects in a computer environment was at least as effective as the conventional manipulation of the actual physical object.

In similar research projects, Cavalcanti et al. (2004) and Hildebolt and Vannier (1998) explored the accuracy of anthropometric measurements of the skull using three-dimensional CT volume rendering, and compared the computer-based measurements against traditional physical measurements for craniofacial landmarks. Cavalcanti et al. (2004) reported no significant difference between interobserver and intraobserver measurements of the 3-D CT images, and both authors demonstrated that no statistically significant difference was found between the computer-based and physical measurements. In conclusion, the anthropometric measurements taken using 3-D CT volume rendered images were found to be highly accurate and precise for applications to osteological material in anthropological research (Cavalcanti et al., 2004; Hildebolt and Vannier, 1988).

Post-mortem investigations in both modern and archaeological contexts are increasingly being assisted by CT and three-dimensional reconstructions as a result of the demonstrated high degree of accuracy and reproducibility of these methods (Dedouit et al., 2007). In an investigation to assess the potential of CT for anthropological identifications in forensic cases, the results of two techniques, multislice computed tomography (MSCT) and dry bone study, were compared by Dedouit et al. (2007). Both techniques were used to determine the sex, age, stature, and ancestry of a severely charred individual whose body was found subsequent to a house fire. Sex was determined first using the traditional visual morphological criteria of the pelvic bone. Two and three-dimensional reconstructions of the pelvis produced from the CT data were then interpreted using the same reference parameters for dry bone. Metric sex determination from the scapula, humerus, and femur was also carried out using both dry bone and CT measurements and the results of the sex determinations for each of the two techniques were compared. Age, stature, and ancestry were similarly assessed using their respective dry bone protocols, and results were also compared to the dry bone analysis. Dedouit et al. (2007) reported that the two techniques, dry bone study and CT imaging, reached the same conclusions concerning the sex of the individual, suggesting that CT is a useful technique for the study of metric and morphological sexing criteria. The conclusions for the estimation of age were also as successful as those reached for sex, whereas stature and ancestry could not be adequately assessed in the dry bone study; however, the stature assessed from the CT images was only slightly underestimated and ancestry was accurately determined based on CT measurements of the sacrum. This case illustrates not only the potential of CT for the rapid identification of individuals in forensic contexts, but also the value of CT for assessing biological profiles, specifically sex, from extremely fragile or partially decomposed human remains.

Although the case study published by Dedouit et al. (2007) has yielded promising results for producing biological profiles from the fragmentary human skeleton using advanced medical imaging techniques, the reviewed literature provides very few studies which have utilized CT and 3-D imaging techniques to assess skeletal sex differences. There are, however, a small number of published validation studies which have investigated the value and accuracy of two-dimensional and three-dimensional CT techniques for determining sex (Uysal et al., 2005; Akansel et al., 2008). For example, Uysal and colleagues (2005) randomly selected 100 (48 males, 52 females) individuals from a Turkish population who had temporal bone CT scans for the purpose of estimating sex using 3-D CT measurements of the foramen magnum. Seven measurements of the foramen magnum were modified for the 3-D volume rendered images from nine variables previously defined by Giles and Elliot (1963) and Holland (1986). Holland's (1986) research on sex determination using the fragmentary skull has been described in detail above and suggests that the measurements of the occipital condyles and foramen magnum are useful for determining sex, with a range in accuracy between 70-90%. The results of Uysal et al.'s (2005) 3-D CT study were comparable to those published in the earlier work by Holland (1986); however, only three of the seven metric variables were statistically significant in sex determination with an accuracy of 81%.

Several cadaveric and dry bone studies of the petrous portion of the temporal bone, such as the previously discussed work conducted by Graw et al. (2005), Lynnerup et al. (2006), Norén et al. (2005), and Wahl (1981) have indicated that this skeletal element is an important part of the skull for determining sex. Taking note of this, Akansel et al. (2008) evaluated the capability of high resolution computed tomography to determine sex from this specific element. The lateral angle method, described previously by Norén et al. (2005) for cadaveric dry bone studies was modified and evaluated using CT to determine whether or not the accuracy reported in the earlier literature, which is discussed in detail above, could be reproduced. The lateral angle of the internal acoustic meatus was measured using axial slices of high resolution CT scans of the temporal bone from 92 patients (45 males, 47 females) who underwent CT as part of a clinical work up. Akansel et al. (2008) determined that the mean lateral angle, as measured from the CT, is greater in females than in males, with a statistically significant difference in values of $45.5^{\circ} \pm 7.1^{\circ}$ and $41.6^{\circ} \pm 6.7^{\circ}$ respectively. Due to a significant overlap in the range of measurements, Norén et al.'s (2005) published cut-off value of 45° used to differentiate males and females could not be supported. Although the results of this study did not reach the same conclusions as the earlier study done by Norén et al. (2005), Akansel et al. (2008) reported that measurements of 35° and lesser were 93.6% specific for males and measurements of 60° and greater were 97.7% specific for females. These results indicate that CT measurements of the lateral angle of the internal acoustic canal can be used in place of direct anatomic measurement; however, as a result of the large range of overlap between the sexes, these measurements should be considered as supportive, and not decisive, evidence for determining sex. In a review of the literature on this subject, it appears as if this is the first study to examine sex differences using CT of the temporal bone.

Within the last decade or so, many anthropological investigations of sex, particularly those focused in archaeology and fossilized human remains, have been restricted by limited access as a result of the fragility of, and need to preserve ancient human remains (Recheis et al. 1999). CT offers anthropological investigators an additional technique for sex determination while preserving the integrity of skeletal remains, and provides accurate and rapid results for forensic experts seeking to positively identify the remains of unknown individuals. Until the introduction of CT to anthropology, the visualization and examination of the internal morphology and structures of skeletal remains, especially the skull, were not possible without causing significant permanent damage (Recheis et al., 1999; Weber et al., 1998). Structures of the skull, such as the petrous portion, which have the potential to offer much information on the sex of an individual have become increasingly accessible, and the possibilities for acquiring data for more advanced morphometric analyses have increased with the use of medical imaging technologies (Akansel et al., 2008; Weber et al., 2001). In fact, Vannier et al. (1985) have suggested that the precision in measurement that can be obtained from complex geometric shapes, such as the skull, using 3-D imaging software is extremely difficult to obtain when using traditional forms of metric analysis.

Compared to traditional anatomical study, the use of medical imaging technologies has several advantages: they are non-invasive, bones can be visualized in situ, data can be collected and skeletal elements manipulated with minimal to no physical handling, and CT images and subsequent 3-D data can be stored for re-analysis and re-interpretation by future generations (Weber, 2001). Therefore, it is surprising to find a significant lack of discussion on the use of medical imaging technology in the sex determination literature. Through the work of Akansel et al. (2008), Dedouit et al. (2007), and Uysal et al. (2005) it has clearly been illustrated that the application of Virtual Anthropology to research on sex determination holds a significant amount of promise for physical anthropology. Further research in this area is needed and has the potential to improve the current methods and techniques used for assessing sex differences in the human skeleton.

CONCLUSIONS

The identification of human skeletal remains is an important aspect of forensic and anthropological investigations (Günay and Altinkök, 2000). The correct determination of sex is of fundamental importance both for personal identification in forensic anthropology, as well as for palaeodemographic studies in archaeology and physical anthropology (Bruzek, 2002; Graw et al., 1999; Mays and Cox, 2000; Scheuer, 2002). The most reliable estimations of sex are achieved through the examination of as many skeletal features as possible, and by employing all available methods of analysis (Bass, 1995; Buikstra and Ubelaker, 1994; Byers, 2002; Krogman and İşcan, 1986; Mays and Cox, 2000; Rogers, 2005).

Skeletal indicators of sex can be evaluated using a number of available methods that have been developed for research in both archaeological and forensic contexts. In the above review, these methods have been described in detail and include: the analysis of selected morphological features that differ visually between males and females, metric techniques for assessing dimorphic dimensions, and statistical approaches such as discriminant function and logistic regression analysis (Albanese, 2003; Buikstra and Ubelaker, 1994; Rösing et al., 2007; Stewart, 1979; Wienker, 1984). A combination of approaches that bring together both morphological and metric methods with traditional and recently emerging anthropological techniques is recommended by many researchers and is advocated in the literature, educational textbooks, and training manuals specific to human osteology and forensic anthropology (Bass, 1995; Buikstra and Ubelaker, 1994; Byers, 2002; Krogman and İşcan, 1986; White, 2000).

The most reliable results for the determination of sex come from a thorough examination of the intact and complete skeleton (Krogman, 1962; Krogman and İşcan, 1986; Mays and Cox, 2000; Rogers, 2005; Stewart, 1979; Uysal et al., 2005). Stewart (1979), and Krogman and İşcan (1986) have claimed that when the entire skeleton is available for analysis, sex can be determined with 90-100% accuracy. However, archaeologists and anthropologists do not always have the luxury of dealing with complete and unfragmented remains; therefore, the development of diagnostic techniques to increase the confidence and accuracy of sex determination for fragmentary and incomplete skeletal remains has become increasingly important. The highest diagnostic value can be attributed to those specific skeletal elements which have high rates of survivability in both forensic and archaeological circumstances, such as the cranial base and, more specifically, the petrous portion of the temporal bone, which often survives when many other indicators of sex do not (Akansel et al., 2008; Graw et al., 2005; Lynnerup et al., 2006; Norén et al., 2005; Wahl and Graw, 2001).

To address these issues of skeletal preservation facing archaeologists and anthropologists, researchers have begun to examine the utility and application of CT to various skeletal structures, and the ability to determine sex through applying innovative medical technologies to previously developed techniques (e.g. Akansel et al., 2008; Uysal et al, 2005). This kind of research will provide many benefits to skeletal sex determination within the study of human osteology, as well as introduce new possibilities for the analysis of fragile or fragmentary human remains. It may also allow for a better understanding of the sexual dimorphism of different aspects of the human skeleton, and may increase the confidence of the osteologist in determining skeletal sex in both archaeological and forensic situations.

With the increasing capability of medical imaging and computer assisted analyses discussed above, researchers will not only be able to perform the traditional range of osteological measurements but, in addition to these measurements a vast amount of information on the internal structures of the skeleton, specifically the cranium, can be obtained without any manipulation or destruction of human remains (Aubin et al., 1997; Cavalcanti et al., 2004; Hildebolt and Vannier, 1988; Smith et al., 2002; Telmon et al., 2005; Uysal et al., 2005; Weber, 2001; Weber et al., 1998). Furthermore, computer-assisted analyses may improve both the efficiency and accuracy of measurements for the determination of sex through the standardization in methodology offered by computerized measurement programs. CT scans and 3D-analyses of human skeletal remains have opened up new possibilities for virtual, touch-less research in human osteology and anthropology as well as the ability to share data and results on the same specimen(s) in different labs across the world (Weber, 2001).

Chapter III: Materials and Methods

The primary goal of this research is to evaluate the usefulness and reliability of the petrous portion of the temporal bone for determining the sex of an individual. The principal studies examined include those of Norén et al. (2005), Lynnerup et al. (2006), and Papangelou (1975). As such, the methods developed for this study are modified from the methods described in the previous research by these authors.

Materials

The data for this study are the computed tomography (CT) scans of 95 randomly selected individuals of known age and sex, with an approximately equal distribution of sexes, which were provided by the Department of Forensic Medicine at the University of Copenhagen, Denmark. These modern forensic scans were obtained post-mortem. All personal information regarding the individuals was anonymized. Age and sex for each individual was recorded independently and only made available for this project upon the completion of data collection

The CT scans which were used for the collection of data were selected based on the quality of the scan and the ease of identification of the internal acoustic canal and its surrounding anatomical structures. Individuals with severe head tilt were excluded from the study as this resulted in the significant warping of the images which displayed the internal acoustic canal (Akansel et al., 2008). In addition, any CT data sets which did not clearly illustrate the canal opening, as well as the canal apex, were also excluded. As a result of these potential sampling issues, from the original CT sample of 95 individuals, 55 individual CT data sets were used for this investigation.

The CT scans were obtained using a multislice Siemens Somatom Sensation 4 scanner. Axial images covering only the skull were obtained using the following parameters: matrix: 512 x 512, kV: 120, mAs: 169.5, algorithm: H20s. The slice thickness was 2mm for the majority of the sample with a small sub-sample of individuals at 1mm (n=4) and 0.5mm (n=2). The field of view varied from 19.00 cm to 28.80 cm, and the pixel size varied from 0.371 mm to 0.516 mm (Appendix I).

Methods

1. Importing and Editing the Images in MIMICS

The raw CT data were provided in the digital image and communications in medicine (DICOM) image format. The CT data in DICOM format were analyzed using Materialise MIMICS version 12.1 in the Bioanthropology Digital Image Analysis Laboratory at the University of Manitoba, Canada. MIMICS provides a range of segmentation, editing, 3-D rendering, and measurement tools that allow for the selection of a region of interest, and the acquisition of digital computer-based measurements for detailed 2-D and 3-D analyses. MIMICS allows for the separation of bone and soft-tissue by means of grey-scale thresholding and manual editing on the single CT-scan slices. The thresholding option identifies different tissues based on Hounsfield values, whereas the segmentation of specific regions of interest often requires manual efforts using a selection of image editing tools provided by the MIMICS program.

After successfully importing the CT data, threshold values were selected isolate the bone from the surrounding soft tissue using Hounsfield gray-scale units (HU) (Figure 3.1). The threshold values for adult bone were selected based on the recommended values for bone density provided by the MIMICS program. The threshold values were set to a level of 226 and a window of 3071 HU and the contrast levels were set to the values provided by MIMICS for bone with a minimum of -1024 HU and a maximum of 1650 HU. The same approximate values were applied for each individual CT scan.

FIGURE 3.1 Before and After Thresholding a CT Scan

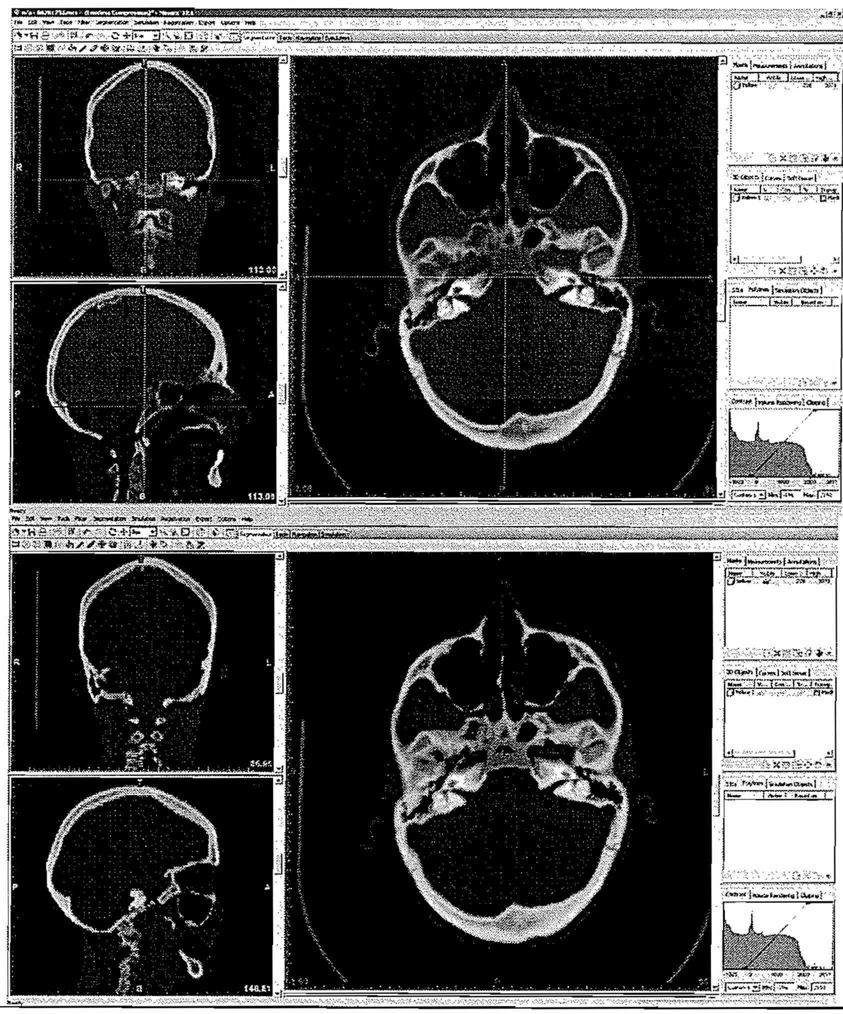

Figure 3.1: The top image illustrates a CT scan prior to the thresholding process. The bottom image illustrates the CT scans after the thresholding is complete. (226-3071 HU)

All of the pixels with grey values within the provided threshold range were highlighted using a coloured mask, and subsequently segmented from the surrounding tissue. Following the thresholding, a manual segmentation of the skull mask was performed on the single CT-scan slices that contained the internal acoustic canal.

The pixels that represent air space, but are in close proximity to the bony walls of the internal acoustic canal were, in almost every case, included in the skull mask as bone during the thresholding process. This was likely caused by the loss of bone to air contrast and partial volume artifacts as a result of the low resolution and slice thickness of the CT scans. The skull mask, then, had to be manually edited using the provided segmentation tools. Using these tools, specific pixels were erased, drawn, or thresholded on the single, axial 2-D images until the canal was clearly visible as an open region on the mask, and this region replicated the shape of the canal on the original CT image when the mask was turned off. This was achieved by magnifying the specific region of interest, editing the mask according to shade differences in the coloured pixels, and by repeatedly turning the mask on and off to better delineate the bony borders of the canal (Figure 3.2). This process was repeated for both the left and right sides, and for each individual slice within the data set that displayed the canal.

FIGURE 3.2 Manual Segmentation of the Internal Acoustic Canal

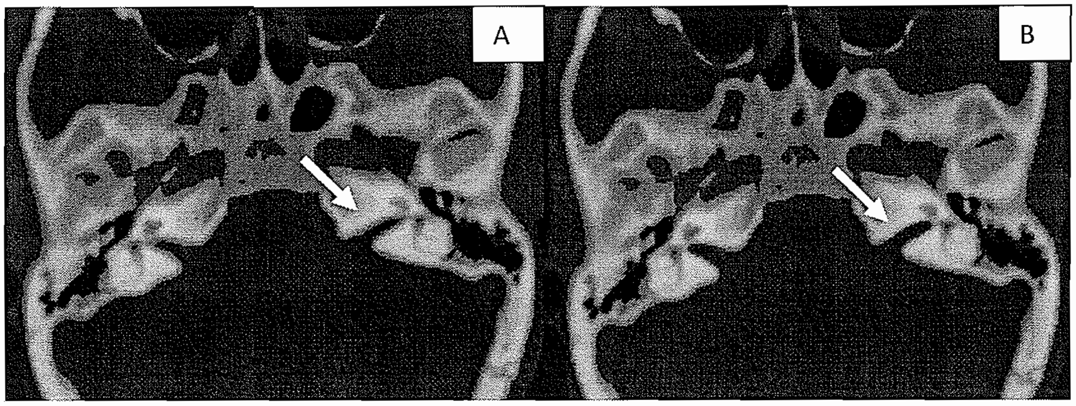

Figure 3.2: "A" illustrates the internal acoustic canal after the thresholding, but prior to manual segmentation. "B" illustrates the canal after the manual segmentation is complete.

Once the manual editing of the internal auditory canal was complete, a new mask was produced using the "cavity fill" tool, which highlights all of the pixels except for those included in the mask of the skull. This new mask, represented by a separate colour, was then cropped to include only those pixels found inside of the canal as well as those pixels located immediately surrounding the opening of the canal along the surface of the facies posterior of the petrous bone.

This created a 2-D negative, or cavity fill, of the region of interest. The mask of the skull was then turned off and, if necessary, the new mask was edited further to fit the shape of the canal as accurately as possible. This process was completed separately for the left and right canals so as to produce two individual cavity fill masks for each side. The completed cavity fills were then used as the basis for the creation of a polyline. The polyline tool in the MIMICS program is used to outline the highlighted pixels of the masks with a continuous line. Polylines were produced for the left and right cavity fill masks and, subsequently, the masks could be turned off leaving the original CT image and an outline (the polyline) of the internal acoustic canal (Figure 3.3). It must be noted that because the pixels are square, the polyline presents in a stepped form and is not a smooth outline; however, this line provides an alternative to the blurred image for taking the necessary 2-D measurements of the internal acoustic canal.

FIGURE 3.3 Creating a Cavity Fill and a Polyline

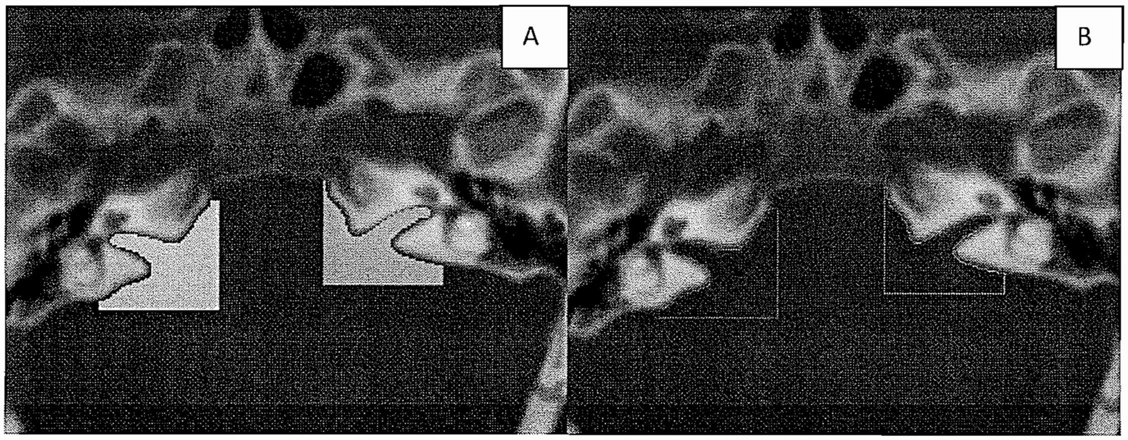

Figure 3.3: "A" depicts the creation of the cavity fill masks created based on the manually edited canals. "B" illustrates the creation of the polylines based on the outline of the cavity fill masks.

2. The Lateral Angle Method

As has been discussed, the lateral angle method of the internal acoustic canal was primarily developed by Wahl (1981) and is based on the most proximal part of the internal acoustic canal at the location of the medial opening. In the previous methods developed by both Norén et al. (2005) and Graw et al. (2005), a silicone-based casting material is inserted in the internal acoustic canal and is left to set. It has been noted by Norén et al. (2005) that the cast must reach the most distal part of the canal; otherwise, the cast may be too short to provide a reliable angle. After the cast has set, it is removed from the petrous bone and bisected to reduce the three-dimensional figure to two dimensions in order to measure the angle of the cast precisely (Norén et al., 2005; Graw et al., 2005). In the methods of Norén et al. (2005), the bisected cast is placed on a protractor and the lateral angle is determined. The base area of the cast is considered as a horizontal line when measuring the angle and the angle is read off in 5° increments. Graw et al. (2005) took a different approach to measuring the lateral angle and placed the bisected halves of the negative casts face down on a photocopy machine and copied them. The lines which form the angle are then drawn directly onto the paper copies. The base line is drawn to run along the posterior surface, ignoring local unevenness, and the second line is made along the lateral edge of the cast following this edge as closely as possible. The angles of both halves of the cast are measured using a normal quadrant and the median value is determined. The aim of the present study is to evaluate if the same discrimination between the sexes can be made with the lateral angle method by using multislice computed tomography scans of the skull. The lateral angle method used herein closely resembles that which was used by Akansel et al. (2008) in a similar work recently published in the forensic literature. The lateral angle was measured on the axial images of the skull at the temporal bone using a method modified from Norén et al. (2005). In order to replicate the bisect of the cast in the original studies, the CT slice that was selected, among those which displayed the canal, was the one on which the apex of the canal was most pointed, and the incudomalleal joint was clearly visible and retained the shape described by Akansel et al. (2008) (ice cream in cone shape) (Figure 3.4). Any scans that did not meet this protocol were not included in the study.

FIGURE 3.4 Selecting an Appropriate CT Slice for Measurement

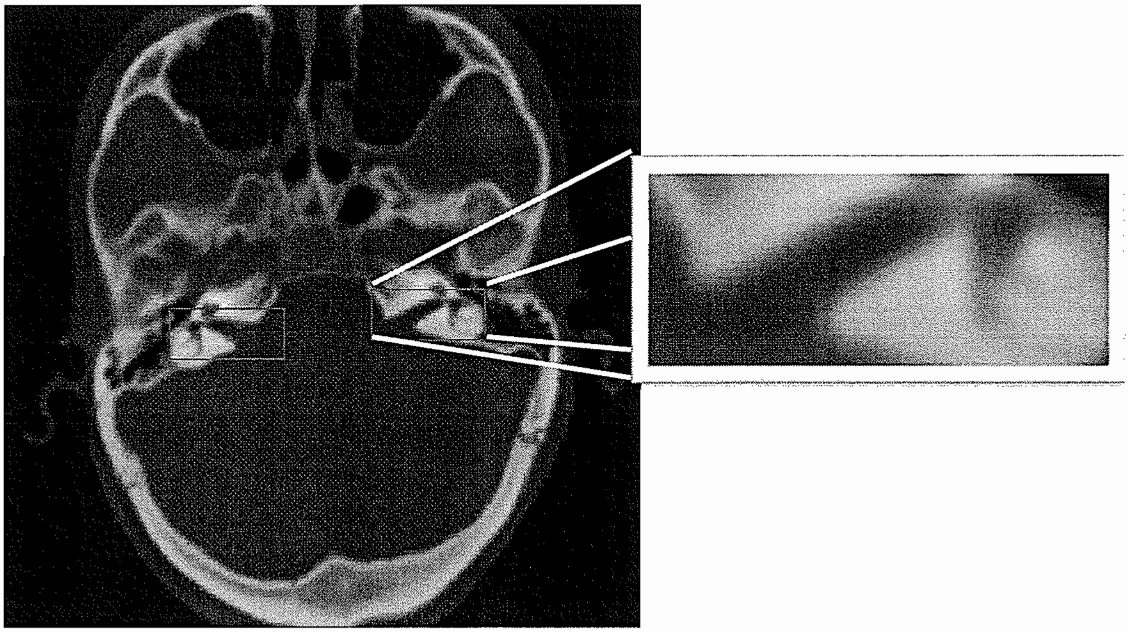

Figure 3.4: Depicts the CT image displaying the apex and the incudomalleal joint that was used to obtain the 2-D measurements

Using the tools provided in MIMICS, the base line was drawn onto the axial image of the selected slice and connected the anterior and posterior lips of the opening of the meatus. The second line that was placed to create the lateral angle connected the anterior lip of the meatus with the most anterior point of the lateral wall of the canal (Akansel et al., 2008). Once these lines were placed, the "measure angle" tool was selected from the MIMICS toolbar and the lines were traced over to determine the resultant angle (Figure 3.5).

FIGURE 3.5 Measuring the Lateral Angle

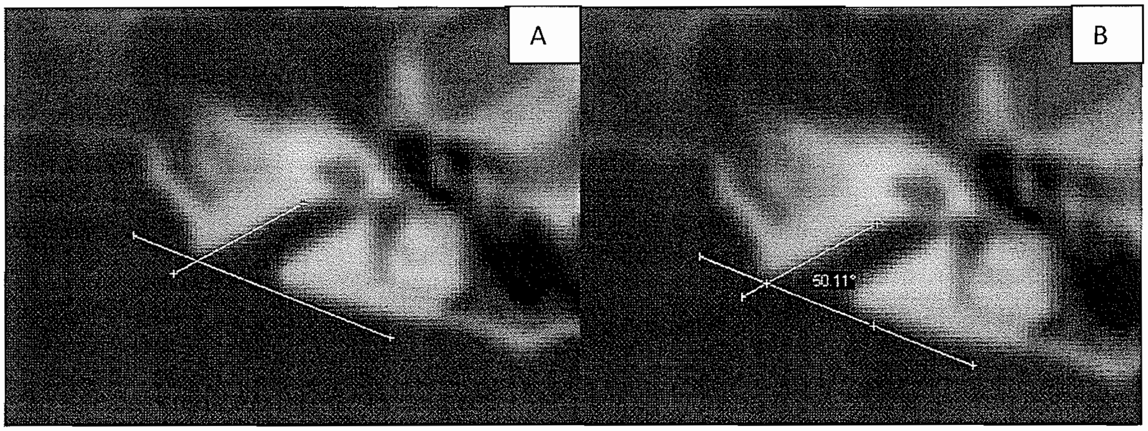

Figure 3.5: "A" shows the placement of the lines to create the lateral angle. "B" illustrates the determination of the lateral angle.

Although it has been documented previously that there is a lack of significant difference between the left and right temporal bone measurements (Norén et al., 2005), both the left and right lateral angles were measured for the majority of cases in this investigation. For those cases which only met the described protocol on one side, only that side was used for acquiring measurements.

It is also important to note that the polylines created in the previous editing process were not used during the collection of data for the lateral angle as part of the objective here was to validate the reproducibility of those methods previously published by Akansel et al. (2008). Although the methods used here closely follow those methods developed by Akansel et al. (2008), it should be noted that the previous study measured left sides only using 1mm axial slices of the temporal bone obtained using a helical CT scanner. The present study, however, uses 2mm axial slices of the skull obtained from a multislice CT scanner, with measurements taken from both the left and right petrous bones.

3. The Diameter Method

The development of the lateral angle method for sex determination has led to the testing of an alternative method for assessing sex from the petrous bone: the diameter of the medial opening of the internal acoustic canal. In a study conducted by Lynnerup and colleagues (2006) the blunt ends of ordinary metal drills are placed into the internal canal opening in order to determine the diameter. The drill ends had diameters of 1.0-10.0 mm in 0.5 mm increments and all of the drills were also measured by digital high precision calipers as a control. The diameter was then recorded by determining which drill best corresponded with the size of the canal opening. In other words, the drill end that determined the diameter had to be completely surrounded by bone (Lynnerup et al., 2006).

In order to maintain consistency within the methods in the present study, the protocol for the selection of the appropriate CT slice from which to take the diameter measurements is the same as that of the lateral angle method. Thus, the measurements for the diameter of the internal acoustic canal were taken from the same slice number as the lateral angle. In an attempt to take the most accurate diameter measurements possible, the area of the canal on the CT image was magnified; however, as a result of the resolution of the CT scans, the pixelation of the images became more apparent and the outline of the canal appeared increasingly blurred. This resulted in an inability to appropriately visualize the outline of the canal as the image displayed no sharp edges. Although the measurements of the diameter were limited by this issue, a methodological compromise was made by turning on the polylines created during the earlier editing process. The polyline provided an alternative for measuring the outline of the canal as it acted as a guide to delineating the borders of the canal rather than attempting to place measurement points onto the blurred image.

The base line that was placed to connect the anterior and posterior lips of the opening of the meatus in the lateral angle method was also used as the base line from which three separate diameters were measured. The first diameter that was recorded was the diameter of the opening of the canal which was determined to be the distance between the location at which the base line crossed over (or connected with) the polyline at the posterior lip and the location in which the base line crossed the polyine at the anterior lip.

Two additional measurements of diameter were also taken inside of the canal at distances of 1 mm and 2 mm from the opening, or the base line. A 2 mm stop point was decided upon based on the observation that the majority of canals began to curve beyond a 2 mm distance into the canal. This curve would have impeded an object, such as a drill end, from being inserted any further, preventing diameter measurements beyond this point. Since the objective here is to validate the previously published literature (Lynnerup et al., 2006), it was decided that measurements beyond 2 mm were not necessary for this study.

The 1 mm and 2 mm diameters were taken parallel to the base line by measuring the distance between the lateral and medial walls determined by the polyline. This was achieved by creating two lines, perpendicular to the base line, on either side of the canal using the "measure angle tool". Distances of 1 mm and 2 mm from the base line were then measured onto each of the perpendicular lines, which were then connected to create the two parallel lines. The diameters at 1 mm and 2 mm were then taken by measuring the distance between the lateral and medial walls where the parallel lines met with the polyline (Figure 3.6). These measurements were recorded and the process was repeated for each of the left and right sides.

FIGURE 3.6 Measuring the Diameter

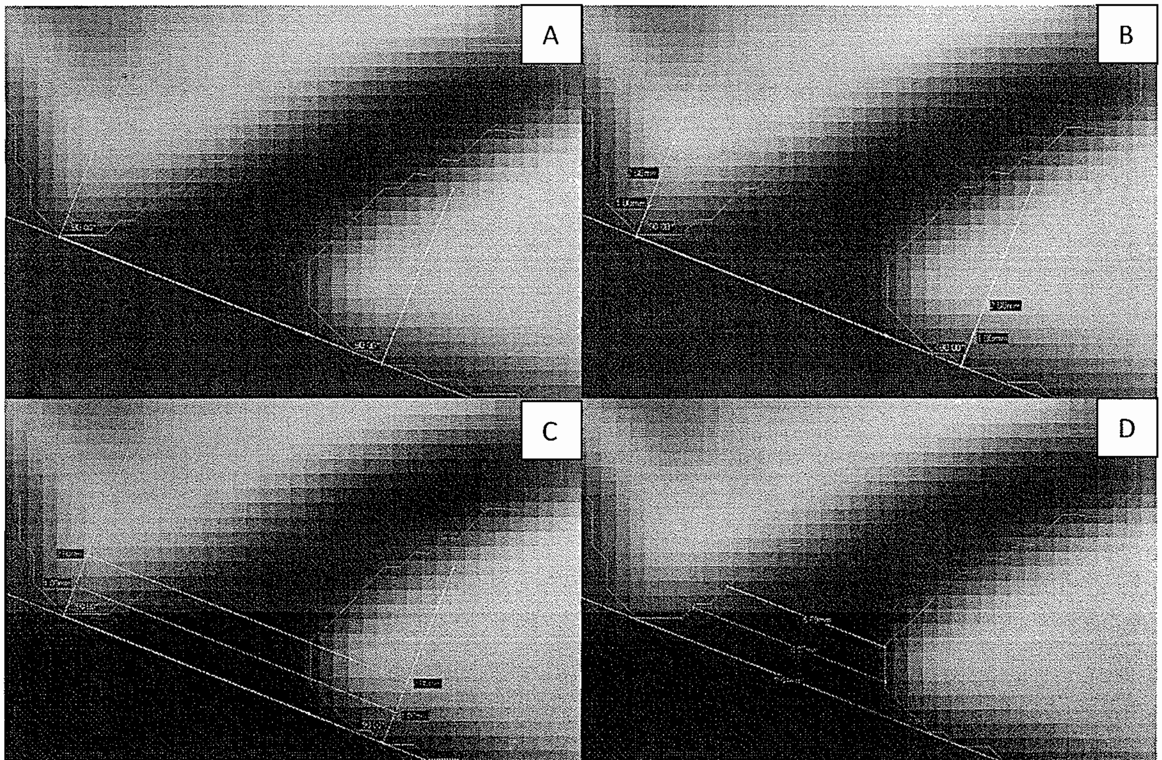

Figure 3.6: "A" illustrates the creation of the perpendicular lines from the original base line. "B" shows the placement of the measurement points at 1mm and 2mm into the canal. "C" depicts the creation of the lines parallel to the base line at 1mm and 2mm into the canal. "D" illustrates the measurement of the three diameters from the lateral wall of the polyline to the medial wall of the polyline by tracing the parallel lines.

It is important to note that the reduced resolution in the sagittal and coronal planes of the current CT data set resulted in a staircase effect and an inability to appropriately visualize and/or edit the canal for accurate 2-D measurements of the vertical diameter. This phenomenon is the result of CT scanner anisotropy. The option of creating a three-dimensional (3-D) image of the skull and/or the canal for taking the vertical diameter measurements would not have resolved the issue of potential measurement error as three-dimensional images are also strongly influenced by CT scanner anisotropy (Vannier et al., 1985).

A CT scanner is an anisotropic imaging system in which the best image resolution is in the plane of section which, in the present study, is the axial plane. The exactness of detail that can be obtained in a 3-D model is dependent upon the amount of CT data and the resultant image resolution (Lambrecht et al., 1993). Reduced resolution in the orthogonal planes is directly related to the slice thickness of the CT scans. Because the large majority of the current data was obtained at a slice thickness of 2mm, the resolution in the coronal plane, along with the reconstructed three-dimensional images of the petrous bone, did not contain enough detail for locating landmarks or visualizing the borders of the canal in order to take accurate measurements of the vertical diameter. In addition, because the internal acoustic canal is a particularly small structure, and the CT slice thickness was 2mm, the canal was only visible on 2-3 slices in each individual. This resulted in a flattened negative cast and/or a significantly flattened canal in the petrous portion, rather than the characteristic cone shape, for a large majority of individuals when the CT data were rendered in 3-D. Thinner CT slices would improve this resolution issue for the orthogonal planes (Rydberg et al., 2000)

4. The Lateral and Medial Lengths Method

In previous studies done in the early 1970's, exact casts of the canal were taken by filling the internal acoustic canal with Light Bodied Kerr Permlastic, which was inserted using a syringe. After the Permlastic was set, the casts were removed and measurements were taken to the nearest millimetre (Papangelou, 1972).

In the research conducted here, the same slice selection protocol used for the previous two methods was also used to obtain measurements from the canal walls, with the aim of remaining consistent for all of the methods. This particular slice was also ideal for taking the length measurements as it displays the apex, which is an anatomical feature of the canal that is necessary for replicating the method of Papangelou (1972) as closely as possible.

Using the same base line that was placed for the lateral angle, and subsequently used for measuring the diameters of the canal, the lateral and medial lengths were taken using two separate approaches: the triangular length and the polyline length. The starting points for the measurement of each of the lateral and medial walls for both of these approaches were determined by locating the point at which the base line intersected with the polyline at both the posterior and anterior lips of the canal opening (Note: these are the same points that were used to measure the diameter of the canal opening in the previous method).

For measuring the lateral triangular length of the internal acoustic canal, the "measure distance" tool was used to connect the point placed on the polyline at the anterior lip of the opening to a second point on the polyline placed at the apex of the canal. The apex of the canal was determined to be the point at which the polyline came to a tip, and began to change direction from an ascending line to a descending line (Figure 3.7). A similar process was repeated for the medial length, with the starting point at the posterior lip of the opening, and ending at the pre-determined apex of the canal. These lengths were then recorded.

FIGURE 3.7 Measuring the Triangular Lengths

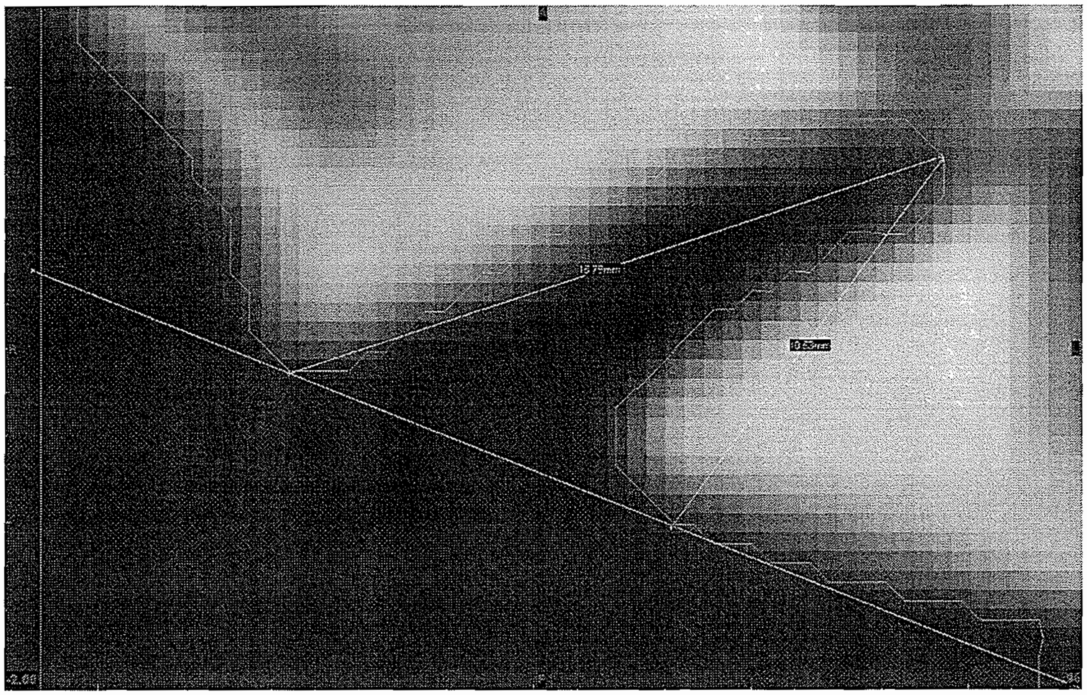

Figure 3.7: The lateral and medial triangular lengths are measured from the base line at the canal opening to the apex.

The same points that were determined for taking the triangular length were also used as the start and end points for measuring the lateral and medial lengths using the polyline approach; however, rather than directly connecting these two points with a straight line, the polyline was traced over using the "measure distance" tool. Because the polyline was not a smooth outline, but rather the summation of several stepped lines, each individual line that made up the polyline from the lip to the apex for each of the lateral and medial walls had to be measured. The sum of the values from all of the individual lines was determined for both walls to obtain the polyline lengths (Figure 3.8). These results were then recorded, and the triangular and polyline approaches were completed for both the left and right internal acoustic canals.

FIGURE 3.8 Measuring the Polyline Lengths

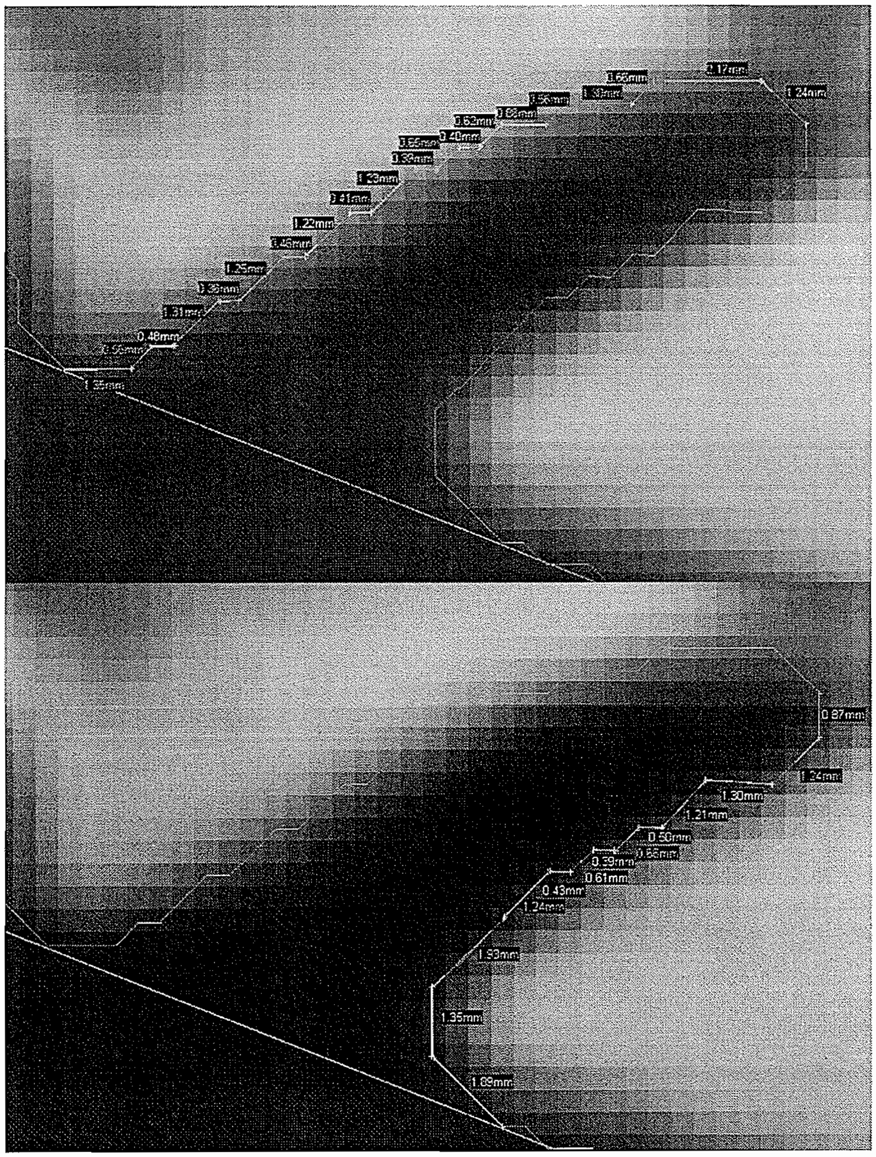

Figure 3.8: The image at the top illustrates the lateral polyline length by measuring the length of each stepped aspect of the polyline. The bottom image illustrates the same method for the medial length

5. Testing the Reliability of the Previously Published Methods

First, in order to test the reproducibility of the collected measurements, 10 cases were randomly selected for intra-observer error testing. The CT data was opened in its original unaltered format and the CT slices which met the protocol outlined above were selected. This test involved redoing the entire procedure outlined above (thresholding, manual editing, cavity fill, polyline creation, and measuring). The intraobserver test was performed with a 2-week interval between the original and re-tested measurements. This test was also carried out without knowledge of the true sex of the individuals.

After completion of the intraobserver error testing, the results of each method were then compared against known sex. Sex was predicted for the lateral angle method following the sectioning point reported by Norén et al. (2005): angles of 45° or more denoted females, and angles below 45° denoted males. These results were then compared against known sex to determine the predictive accuracy of the published 45° sectioning point for the lateral angle method (Norén et al., 2005). Frequency tables were created to compare the distribution of the lateral angles measurements for each sex.

Lynnerup et al. (2006) reported disappointing results for the predictive power of the diameter in terms of correct sexing. Nonetheless, based on the distribution of diameter size between males and females, Lynnerup and colleagues (2006) published the following sectioning points: a diameter of less than 3.0mm is indicative of females and a diameter greater than, or equal to 3.5mm is indicative of males. In addition, Lynnerup et al. (2006) also reported a second set of cut-off points for predicting sex. A diameter of 2.5mm is indicative of females, a diameter of 4.0-4.5mm is indicative of males, while a diameter of 5.0mm or more was undecided (two cases had diameters of 5.0mm or more, and one was a male and the other a female). Sex was predicted for both sets of published sectioning points and compared against known sex. Frequency tables were created using the current data to analyze and compare the distribution of each of the measurements in an attempt to determine if a difference exists between the distribution of male and female canal diameters.

The measurement distributions for the lateral and medial lengths of the internal acoustic canal walls were compared to the results reported by Papangelou (1975). Papangelou (1975) reported only frequency tables when analyzing the internal acoustic canal for sex differences between the lengths of the lateral and medial walls. Therefore, in order to validate the previously published sex distributions, the measurements collected in the present study were organized into frequency tables for the purpose of comparing the length distributions according to sex from the present results with Papangelou's (1975) previous results.

Chapter IV: Results

Age Distribution

The age distribution for the 55 individuals evaluated in this study ranged from 24-84 years with a mean age of 47.4 years. For the 40 males, age ranged from 24-84, with a mean age of 46.5 years, while the 15 females ranged from 29-81, with a mean age of 49.7 years. Despite the considerably smaller sample of females, the age distribution between the sexes was strikingly similar, and an independent samples t test revealed that there are no statistically significant differences between the male and female mean values for age ($p = 0.442$).

Bilateral Sample

Independent-sample t tests indicated no significant differences in the mean lateral angle size (Table 4.1), diameters (Table 4.2), or length measurements (Table 4.3) between the left and right temporal bones. In addition, no significant differences were found between the left and right sides when controlling for sex in each of the variables. Therefore, in order to remain consistent with the previous research methods, which also documented a lack of significant differences between the sides in this cranial element (Akansel et al., 2008; Lynnerup et al., 2006; Norén et al., 2005), the left side was used to analyze the sex differences for each method. Of the 58 total cases used in this investigation, measurements were taken from both the left and right petrous bones in a total of 40 cases. For the remaining 18 cases, 15 met the protocol outlined for selecting the appropriate CT slice for the left side only and 3 met the protocol for the right side only. Since only the left temporal bone will be used for the statistical analyses, the resultant sample size used for the statistical analysis is 55 individuals. The 3 cases which met the protocol for the right side only were not included. These 55 cases consisted of 40 males and 15 females.

TABLE 4.1 Comparing the Left and Right Means of the Lateral Angle

Group Statistics					
	Side	N	Mean	Std. Deviation	Std. Error Mean
Lateral Angle	Left	55	44.9398	6.91597	.93255
	Right	43	44.6295	7.42396	1.13214

Independent Samples Test										
		Levene's Test		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff.	Lower	Upper
LA	Equal variances assumed	.509	.478	.213	96	.831	.31028	1.45398	-2.57584	3.19640
	Equal variances not assumed			.212	87.131	.833	.31028	1.46676	-2.60501	3.22557

Table 4.1: Results of the independent sample statistics representing a comparison of the means between the left and right sides produced by the lateral angle method for the internal acoustic canal

TABLE 4.2 Comparing the Left and Right Means of the Canal Diameters

Group Statistics

	Side	N	Mean	Std. Deviation	Std. Error Mean
Diameter at the Opening	Left	55	9.8896	1.43179	.19306
	Right	43	9.8707	1.55749	.23751
Diameter at 1mm	Left	55	6.1909	.99111	.13364
	Right	43	6.0909	1.14077	.17397
Diameter at 2mm	Left	55	7.4478	1.17097	.15789
	Right	43	7.4460	1.29665	.19774

Independent Samples Test

		Levene's Test for Equal of Variances		t-test for Equality of Means						
									95% Confidence Interval	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff.	Lower	Upper
Diam at the Open	Equal var. assumed	.338	.562	.063	96	.950	.01894	.30292	-.58235	.62023
	Equal var. not assumed			.062	86.474	.951	.01894	.30608	-.58949	.62736
Diam at 1mm	Equal var.assumed	.390	.534	.464	96	.644	.09998	.21561	-.32801	.52796
	Equal var. not assumed			.456	83.564	.650	.09998	.21937	-.33630	.53626
Diam at 2mm	Equal var. assumed	.022	.881	.007	96	.994	.00177	.24988	-.49424	.49778
	Equal var. not assumed			.007	85.575	.994	.00177	.25304	-.50130	.50484

Table 4.2: Results of independent sample statistics representing a comparison of the means between the left and right sides produced by the diameter method

TABLE 4.3 Comparing the Left and Right Means of the Canal Lengths

Group Statistics					
	Side	N	Mean	Std. Deviation	Std. Error Mean
Lateral Triangular Length	Left	55	15.1053	1.62544	.21917
	Right	43	14.7800	1.53227	.23367
Medial Triangular Length	Left	55	9.7375	1.31359	.17712
	Right	43	9.7209	1.59040	.24253
Lateral Polyline Length	Left	55	16.2167	1.75729	.23695
	Right	43	15.9607	1.59831	.24374
Medial Polyline Length	Left	55	12.0820	1.57248	.21203
	Right	43	12.3309	1.80727	.27561

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff	Lower	Upper
Lat. Tri Length	Equal variances assumed	.026	.871	1.008	96	.316	.32527	.32272	-.31532	.96586
	Equal variances not assumed			1.015	92.640	.313	.32527	.32037	-.31096	.96150
Med. Tri Length	Equal variances assumed	.515	.475	.056	96	.955	.01652	.29339	-.56584	.59889
	Equal variances not assumed			.055	80.859	.956	.01652	.30033	-.58105	.61410
Lat Poly Length	Equal variances assumed	.085	.771	.744	96	.458	.25603	.34393	-.42668	.93873
	Equal variances not assumed			.753	93.763	.453	.25603	.33994	-.41894	.93100
Med Poly Length	Equal variances assumed	.069	.793	-.728	96	.468	-.24893	.34183	-.92746	.42960
	Equal variances not assumed			-.716	83.641	.476	-.24893	.34773	-.94047	.44261

Table 4.3: Results of independent sample statistics representing a comparison of the means between the left and right sides produced by the length methods for the internal acoustic canal

Intra-Observer Error

In order to test the reproducibility of the methods used in this study, intra-observer error testing was carried out on 10 (6 males, 4 females) randomly selected individuals using the left petrous portion. A paired-samples t test was carried out to compare the results of the original and secondary evaluations for each of the variables (Table 4.4). No statistical significance was found between the first and second measurements for the lateral angle ($p = 0.612$), diameter of the opening ($p = 0.267$), diameter at 1mm ($p = 0.230$), diameter at 2mm ($p = 0.868$), lateral triangular length ($p = 0.445$), medial triangular length ($p = 0.648$), lateral polyline length ($p = 0.604$), or the medial polyline length ($p = 0.577$), indicating good intra-observer agreement for each of the previously outlined methods.

TABLE 4.4 Analysis of Intra-Observer Error

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Dev.	Std. Error Mean	Lower	Upper			
Pair 1	Lateral Angle 1 - Lateral Angle 2	.14400	.86608	.27388	-.47556	.76356	.526	9	.612
Pair 2	Diam. of Opening 1 – Diam. of Opening 2	-.18500	.49386	.15617	-.53828	.16828	-1.185	9	.267
Pair 3	Diam at 1mm 1 – Diam at 1mm 2	.22000	.54070	.17098	-.16679	.60679	1.287	9	.230
Pair 4	Diameter at 2mm 1 - Diameter at 2mm 2	-.03100	.57483	.18178	-.44221	.38021	-.171	9	.868
Pair 5	Lat. Tri Length 1 - Lat Tri Length 2	-.17700	.70114	.22172	-.67857	.32457	-.798	9	.445
Pair 6	Med Tri Length 1 - Med Tri Length 2	.05600	.37554	.11875	-.21264	.32464	.472	9	.648
Pair 7	Lat Poly Length 1 – Lat Poly Length 2	-.13700	.80678	.25513	-.71413	.44013	-.537	9	.604
Pair 8	Med Poly Length 1 - Med Poly Length 2	.14700	.80369	.25415	-.42792	.72192	.578	9	.577
Side = Left									

Table 4.4: Results of the paired-samples t test for the analysis of intra-observer error using the left internal acoustic canal.

Lateral Angle Method

Descriptive statistics which summarize the results for the left lateral angle measurements for males and females can be found in Table 4.5. Sex was predicted using Norén et al.'s (2005) sectioning point of 45° (angles less than 45° indicate males; angles greater than, or equal to, 45° indicate females) in order to test the accuracy of this published sectioning point for the current sample. An accurate prediction of sex in the

CT sample in males occurred 20 (50%) times out of 40 while for females the accuracy rate was 60%, or 9 correctly identified females out of 15 cases (Table 4.6). In total, the correct sex was assigned for only 29 cases out of a total of 55 individuals with a resultant overall accuracy rate of 53%. This low predictive value for correct sexing using the previously published sectioning point for the lateral angle (Norén et al., 2005) was disappointing.

TABLE 4.5 Descriptive Statistics for the Left Lateral Angle

Descriptive Statistics								
True Sex		N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Male	Lateral Angle	40	27.52	32.17	59.69	44.2667	7.10987	50.550
	Valid N (listwise)	40						
Female	Lateral Angle	15	26.11	38.67	64.78	46.7347	6.23899	38.925
	Valid N (listwise)	15						

Table 4.5: Results of the descriptive statistics for the left lateral angle measurements by sex

TABLE 4.6 Sex Predictive Value of Norén et al.`s (2005) Lateral Angle Sectioning Point

True Sex * Predicted Sex Crosstabulation					
			Predicted Sex		Total
			Male	Female	
True Sex	Male	Count	20	20	40
		% within True Sex	50.0%	50.0%	100.0%
		% within Predicted Sex	76.9%	69.0%	72.7%
		% of Total	36.4%	36.4%	72.7%
	Female	Count	6	9	15
		% within True Sex	40.0%	60.0%	100.0%
		% within Predicted Sex	23.1%	31.0%	27.3%
		% of Total	10.9%	16.4%	27.3%
Total		Count	26	29	55
		% within True Sex	47.3%	52.7%	100.0%
		% within Predicted Sex	100.0%	100.0%	100.0%
		% of Total	47.3%	52.7%	100.0%

Table 4.6: Crosstabulation results for sex predictive value using the 45° sectioning point published by Norén et al. (2005)

After determining the poor predictive value of Norén et al.'s (2005) 45° sectioning point for the sample of individuals examined in the present study, an independent-samples t test was carried out in order to analyze any potential sex differences in the lateral angle for the data used in this study. The mean value for the lateral angle of the internal acoustic canal was 46.7 ± 6.2° for females and 44.3 ± 7.1° for males (Table 4.5). The mean difference was not statistically significant at (p = 0.242). A second independent-samples t test was performed on the same data set for the lateral angle. This test was conducted as Norén et al. (2005) note that the lateral angle measurements were read off in 5° increments. In order to determine if this made any difference for statistical significance between the sexes, the original measurements for this study, which were taken to 2 decimal places, were rounded to incremental values of every 5° (i.e. 27.50-32.49° = 30°; 32.50-37.49° = 35°, etc.). This made little difference in the mean values from the previous t test with a resulting female mean of 46.7 ± 6.7 and a male mean of 44.1 ± 7.1 (Table 4.7). Again, no statistically significant differences between males and females was found with regard to the lateral angle (p = 0.234). There was also little change in the predictive value of Norén et al.'s (2005) sectioning point of 45° for the sample when measured in 5° increments (Table 4.8). Using these rounded data, a total of 28 out of the 55 cases were correctly sexed resulting in an overall accuracy rate of only 51%, with 18 out of 40 (45%) males and 10 out of 15 (67%) females correctly identified.

TABLE 4.7 Descriptive Statistics for the Lateral Angle Measured in 5° Increments

Descriptive Statistics								
True Sex		N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Male	Lateral Angle	40	30	30	60	44.13	7.061	49.856
	Valid N (listwise)	40						
Female	Lateral Angle	15	25	40	65	46.67	6.726	45.238
	Valid N (listwise)	15						

Table 4.7: Results of the descriptive statistics for the left lateral angle measurements by sex measured in 5° increments

TABLE 4.8 Sex Predictive Value of Norén et al.'s (2005) Lateral Angle Sectioning Point for the 5° Incremental Measurements

True Sex * Predicted Sex Crosstabulation					
			Predicted Sex		Total
			Male	Female	
True Sex	Male	Count	18	22	40
		% within True Sex	45.0%	55.0%	100.0%
		% within Predicted Sex	78.3%	68.8%	72.7%
		% of Total	32.7%	40.0%	72.7%
	Female	Count	5	10	15
		% within True Sex	33.3%	66.7%	100.0%
		% within Predicted Sex	21.7%	31.3%	27.3%
		% of Total	9.1%	18.2%	27.3%
Total		Count	23	32	55
		% within True Sex	41.8%	58.2%	100.0%
		% within Predicted Sex	100.0%	100.0%	100.0%
		% of Total	41.8%	58.2%	100.0%

Table 4.8: Crosstabulation results for sex predictive value using the 45° sectioning point published by Norén et al. (2005) for the lateral angle data rounded to 5° increments

In addition to the statistical tests for the analysis of sex differences in the CT sample, a simple bivariate correlation was run to determine whether there was a relationship between the lateral angle size and age. A Pearson's correlation coefficient indicated no significant linear relationship between the lateral angle and age when the sexes are combined ($p = 0.080$), nor was there any significant correlation when controlling for sex (Table 4.9).

TABLE 4.9 Correlations between Lateral Angle Size and Age

Correlations				
True Sex			Lateral Angle	Age
Male	Lateral Angle	Pearson Correlation	1	.102
		Sig. (2-tailed)		.530
		N	40	40
	Age	Pearson Correlation	.102	1
		Sig. (2-tailed)	.530	
		N	40	40
Female	Lateral Angle	Pearson Correlation	1	.511
		Sig. (2-tailed)		.052
		N	15	15
	Age	Pearson Correlation	.511	1
		Sig. (2-tailed)	.052	
		N	15	15

Table 4.9: Results of the bivariate Pearson correlation for the lateral angle size and age when controlling for sex

When the individuals analyzed in the present study were organized into two separate age groups, those 49 years and younger (n=29; 22 males, 7 females) and those 50 years and older (n=26; 18 males, 8 females), the lateral angle between these two groups yielded a statistically significant difference when the total sample (males and females combined) was analyzed (Table 4.10); however, statistical significance was not reached between the younger and older age groups within either sex when males and females were considered separately (males: $p = 0.053$, females: $p = 0.251$). Finally, an independent samples t test revealed that there were also no statistically significant sex differences in lateral angle size within either age group (49 years and less: $p = 0.341$; 50 years and older: $p = 0.573$).

TABLE 4.10 Comparing the Lateral Angle Size in Younger vs. Older Individuals

Group Statistics					
	Age Category	N	Mean	Std. Deviation	Std. Error Mean
Lateral Angle	<49	29	42.8862	5.66414	1.05180
	>50	26	47.2304	7.55203	1.48108

Independent Samples Test										
		Levene's Test		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig (2-tailed)	Mean Diff.	Std. Error Diff.	Lower	Upper
LA	Equal variances assumed	1.580	.214	-2.429	53	.019	-4.3441	1.78850	-7.9314	-.75690
	Equal variances not assumed			-2.391	46.105	.021	-4.3441	1.81656	-8.00049	-.68786

Table 4.10 : Results for the independent samples T test for younger versus older individuals for the total sample (sexes combined)

Diameter Method

In 2006, Lynnerup and colleagues published several sectioning points for the diameter of the internal opening of the acoustic canal. A diameter of less than 3.0mm is indicative of females and greater than 3.5mm is indicative of males. For a separate set of sectioning points, a diameter of 2.5mm indicates a female, 4.0-4.5mm indicates a male, and a diameter of 5.0mm or more was undecided. Since the drill ends used by Lynnerup et al. (2006) had diameters that increased in 0.5mm increments, the diameters measured from the current sample were rounded from 2 decimal places to 0.5mm increments and both sets of sectioning points were applied to the three different diameter measures. Sex could not be accurately predicted using any of these measurements. Since the diameter measurements for the vast majority of cases in this study, with the exception of 5 individuals (at the 2mm diameter measurement), fell above 5.0mm, the first set of sectioning points predicted that 55 out of the 55 total cases were male for all three of the diameter measures. For the second set of sectioning points, the diameter at the opening and at 1mm into the canal, classified all cases as undecided. At the 2mm diameter measurement this range correctly identified 5 out of 40 (12.5%) males, and classified the remaining 50 cases as undecided. Therefore, the validity of the sectioning points provided by Lynnerup et al. (2006) could not be adequately tested on this sample. Summary statistics which describe the findings for the diameter of the canal opening, diameter at 1mm into the internal acoustic canal, and the diameter at 2mm into the canal are provided in Table 4.11 for the rounded values and Table 4.12 for the original values taken to 2 decimal places.

TABLE 4.11 Descriptive Statistics for the Left Diameter Measurements rounded to 0.5mm Increments

Descriptive Statistics						
True Sex		N	Minimum	Maximum	Mean	Std. Dev.
Male	Diameter at the Opening	40	7.00	14.00	9.9500	1.58842
	Diameter at 1mm	40	5.00	10.50	7.5000	1.23517
	Diameter at 2mm	40	4.00	9.00	6.3000	1.10824
	Valid N (listwise)	40				
Female	Diameter at the Opening	15	8.00	12.00	9.9000	1.10518
	Diameter at 1mm	15	6.00	9.00	7.2333	.86327
	Diameter at 2mm	15	5.00	8.00	5.8667	.93478
	Valid N (listwise)	15				

Table 4.11: Results of descriptive statistics for the left diameter measurements rounded to 0.5mm increments split by sex

TABLE 4.12 Descriptive Statistics for the Left Diameter Measurements

Descriptive Statistics						
True Sex		N	Minimum	Maximum	Mean	Std. Deviation
Male	Diameter of the Opening	40	6.75	13.89	9.8993	1.56703
	Diameter at 1mm	40	4.76	10.46	7.5030	1.25923
	Diameter at 2mm	40	4.23	8.57	6.2883	1.03476
	Valid N (listwise)	40				
Female	Diameter of the Opening	15	7.96	11.65	9.8640	1.03235
	Diameter at 1mm	15	5.61	8.94	7.3007	.91637
	Diameter at 2mm	15	4.80	7.78	5.9313	.84075
	Valid N (listwise)	15				

Table 4.12: Results of descriptive statistics for the original left diameter measurements split by sex.

Since sex could not be predicted using the sectioning points provided in the literature the data, rounded to each 0.5mm, for the diameter measurements for the left side were put into three separate frequency tables to analyze the distribution of the diameters between the sexes (Tables 4.13, 4.14, 4.15 and Figures 4.1, 4.2, 4.3). Independent samples t tests were also conducted for each of the three diameter measures to determine whether or not significant sex differences exist in diameter size for the current CT sample. For the data rounded to match the 0.5mm incremental measurements used in Lynnerup et al. (2006), no statistical significance was found between males and females for the diameter at the canal opening ($p = 0.911$), the diameter at 1mm into the canal ($p = 0.447$), or the diameter at 2mm into the canal ($p = 0.185$). Similarly, no significant sex differences were found for the opening ($p = 0.936$), 1mm ($p = 0.573$), and 2mm diameters ($p = 0.238$) when the original diameter measurements, taken to 2 decimal places, were analyzed.

TABLE 4.13 Frequency Table for the Diameter of the Canal Opening (0.5mm)
FIGURE 4.1 Histogram for the Diameter of the Canal Opening (0.5mm)

Diameter of the Opening-Left Side				
mm	Male No.	%	Female No.	%
7.0	3	7.50	0	0
7.5	0	0	0	0
8.0	5	12.50	1	6.67
8.5	0	0	0	0
9.0	5	12.50	5	33.33
9.5	1	2.50	0	0
10.0	11	27.50	5	33.33
10.5	1	2.50	0	0
11.0	9	22.50	2	13.33
11.5	0	0	1	6.67
12.0	3	7.50	1	6.67
12.5	0	0	0	0
13.0	1	2.50	0	0
13.5	0	0	0	0
14.0	1	2.50	0	0
14.5	0	0	0	0
15.0	0	0	0	0
# of Canals	40		15	

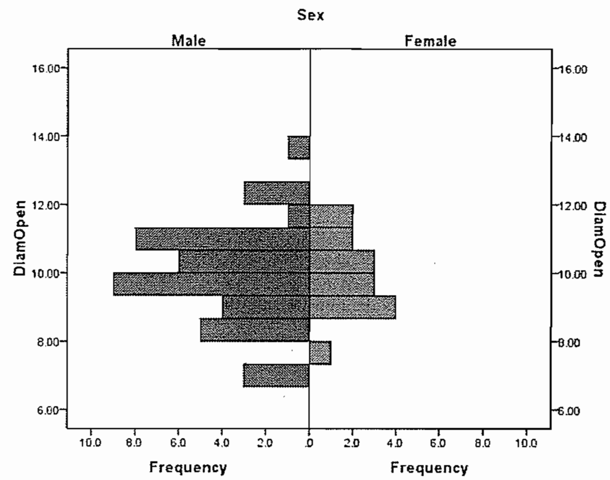

Table 4.13: (Left) Frequency table for diameter of the canal opening split by sex(0.5mm increments)
Figure 4.1: (Right) Histogram illustrating the distribution of the diameter of the canal opening

TABLE 4.14 Frequency Table for the Diameter at 1mm (0.5mm)
FIGURE 4.2 Histogram for the Diameter at 1mm (0.5mm)

Diameter at 1mm-Left Side				
mm	Male No.	%	Female No.	%
5.0	2	5.00	0	0
5.5	0	0	0	0
6.0	7	17.50	3	20.00
6.5	0	0	0	0
7.0	9	22.50	6	40.00
7.5	2	5.00	1	6.67
8.0	11	27.50	4	26.67
8.5	2	5.00	0	0
9.0	5	12.50	1	6.67
9.5	1	2.50	0	0
10.0	0	0	0	0
10.5	1	2.50	0	0
11.0	0	0	0	0
# of Canals	40		15	

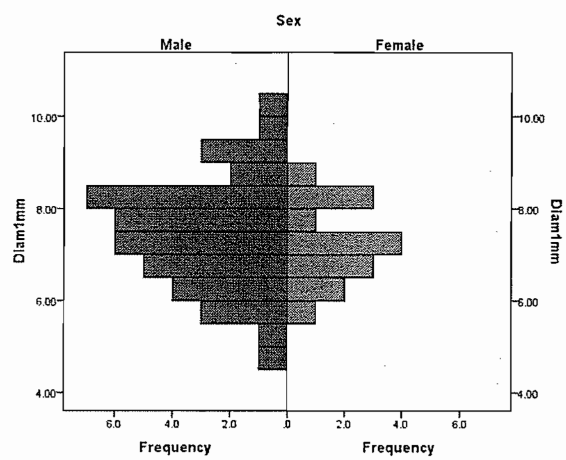

Table 4.14 (left): Frequency table for the diameter at 1mm split by sex (0.5mm increments)
Figure 4.2 (right): Histogram illustrating the distribution of the diameter at 1mm split by sex

TABLE 4.15 Frequency Table for the Diameter at 2mm (0.5mm)
FIGURE 4.3 Histogram for the Diameter at 2mm (0.5mm)

Diameter at 2mm-Left Side				
mm	Male No.	%	Female No.	%
4	1	2.50	0	0
4.5	0	0	0	0
5	10	25.00	6	40
5.5	2	5.00	1	6.67
6	7	17.50	4	26.67
6.5	0	0	1	6.67
7	16	40.00	2	13.33
7.5	0	0	0	0
8	3	7.50	1	6.67
8.5	0	0	0	0
9	1	2.50	0	0
10	0	0	0	0
10.5	0	0	0	0
11	0	0	0	0
# of Canals	40		15	

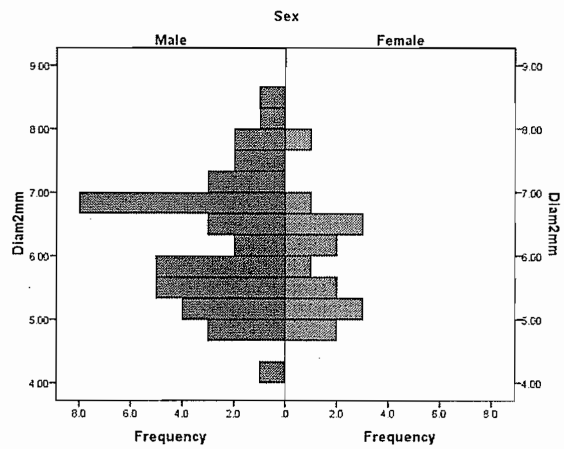

Table 4.15 (left): Frequency table for the diameter at 2mm split by sex (0.5mm increments)
Figure 4.3 (right): Histogram illustrating the distribution of the diameter at 2mm split by sex

In the total combined sample (males and females) Pearson's correlation coefficients indicated that there was no significant relationship between age and the diameter of the canal opening (p = 0.843), age and the diameter at 1mm into the canal (p = 0.671), or age and the diameter at 2mm into the canal (p = 0.664). When controlling for sex, there was no significant linear correlation between age and the diameter at the opening (p = 0.387 for males; p = 0.104 for females) or the diameter at 2mm into the canal (p = 0.943 for males; p = 0.186 for females); however, there was a significant positive correlation between age and the diameter at 1mm into the canal in the female sub-sample (Table 4.16 and Figure 4.4). This correlation was not statistically significant for males (Table 4.16).

TABLE 4.16 Correlations between the Diameter at 1mm and Age

Correlations				
True Sex			Age	Diameter at 1mm
Male	Age	Pearson Correlation	1	-.074
		Sig. (2-tailed)		.651
		N	40	40
	Diameter at 1mm	Pearson Correlation	-.074	1
		Sig. (2-tailed)	.651	
		N	40	40
Female	Age	Pearson Correlation	1	.582*
		Sig. (2-tailed)		.023
		N	15	15
	Diameter at 1mm	Pearson Correlation	.582*	1
		Sig. (2-tailed)	.023	
		N	15	15

*. Correlation is significant at the 0.05 level (2-tailed).

Table 4.16: Correlations between the diameter at 1mm into the canal and age split by sex.

FIGURE 4.4 Scatterplot of the Correlation between the Diameter at 1mm and Age in Females

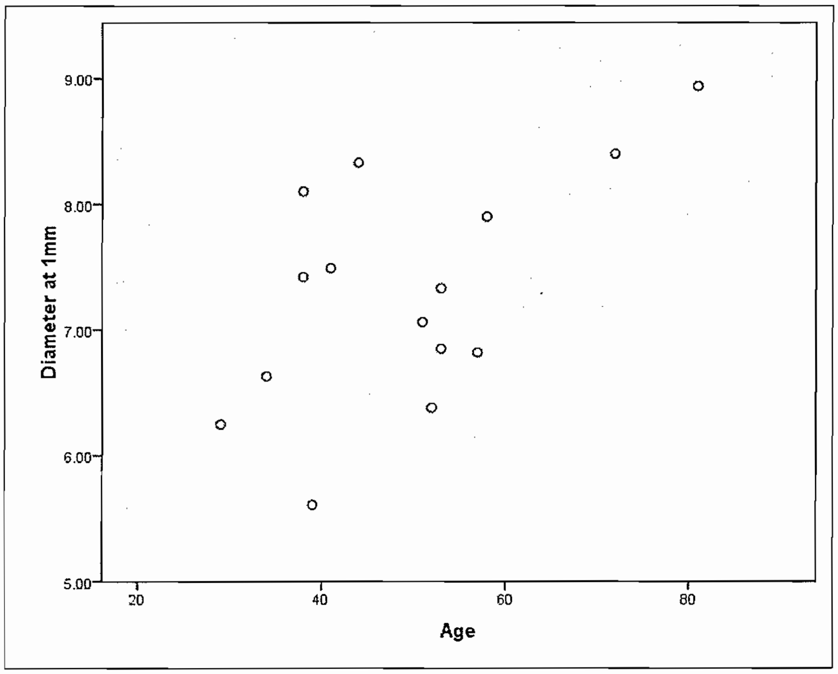

Figure 4.4: Scatterplot representing the correlation between age and the diameter at 1mm into the canal in females

The diameter of the canal opening between the age group up to 49 and the group 50 years and older yielded a statistically significant difference for the total sample when the sexes were combined (p = 0.030) (Table 4.17), and only for the male subjects (p = 0.025) when diameter differences for the canal opening were analyzed for each sex separately (Table 4.18). An additional independent samples t test revealed no statistically significant differences between the sexes in the younger age group (p = 0.461) or the older age group (p = 0.392) for the diameter of the opening. The diameter at 1mm into the canal was statistically significant between the younger and older age groups only in males when the diameter measurements were separated by sex (p = 0.036) (Table 4.19).

TABLE 4.17 Comparing the Size of the Diameter of the Canal Opening in Younger vs. Older Individuals

Group Statistics

	Age Category	N	Mean	Std. Deviation	Std. Error Mean
Diameter at the canal opening	<49	29	10.2959	1.25072	.23225
	>50	26	9.4658	1.50033	.29424

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff.	Lower	Upper
Diam. At canal opening	Equal variances assumed	1.689	.199	2.237	53	.030	.83009	.37113	.08571	1.57448
	Equal variances not assumed			2.214	48.90	.031	.83009	.37486	.07675	1.58343

Table 4.17: Results of an independent-sample T test for the diameter of the canal opening between the age group up to 49 years and the group 50 years and older

TABLE 4.18 Comparing the Size of the Diameter of the Canal Opening in Younger vs. Older Individuals within Males and Females

Group Statistics

True Sex		Age Category	N	Mean	Std. Deviation	Std. Error Mean
Male	Diameter at the canal opening	<49	22	10.3945	1.30733	.27872
		>50	18	9.2939	1.67828	.39558
Female	Diameter at the canal opening	<49	7	9.9857	1.08176	.40887
		>50	8	9.8525	.97569	.34496

Independent Samples Test

True Sex			Levene's Test for Equality of Variances		t-test for Equality of Means						
										95% Confidence Interval of the Difference	
			F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff.	Lower	Upper
Male	Diamat the open	Equal variances assumed	2.796	.103	2.332	38	.025	1.10066	.47190	.14535	2.05596
		Equal variances not assumed			2.275	31.737	.030	1.10066	.48391	.11465	2.08667
Female	Diamat the open	Equal variances assumed	1.272	.280	.251	13	.806	.13321	.53101	-1.01396	1.28039
		Equal variances not assumed			.249	12.258	.807	.13321	.53495	-1.02961	1.29604

Table 4.18: Results of the independent-sample T test for the diameter of the canal opening between the younger and older age groups within each sex

TABLE 4.19 Comparing the Size of the Diameter at 1mm in Younger vs. Older Individuals within Males and Females

Group Statistics

True Sex		Age Category	N	Mean	Std. Deviation	Std. Error Mean
Male	Diameter at 1mm	<49	22	7.8886	1.03371	.22039
		>50	18	7.0317	1.37478	.32404
Female	Diameter at 1mm	<49	7	7.1071	.79179	.29927
		>50	8	7.4725	1.03197	.36486

Independent Samples Test

True Sex			Levene's Test for Equality of Variances		t-test for Equality of Means						
										95% Confidence Interval of the Difference	
			F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff.	Lower	Upper
Male	Diameter at 1mm	Equal var. assumed	2.690	.109	2.250	38	.030	.85697	.38086	.08595	1.6279
		Equal var. not assumed			2.187	30.996	.036	.85697	.39188	.05772	1.6562
Female	Diameter at 1mm	Equal var. assumed	.124	.730	-.760	13	.461	-.36536	.48073	-1.40392	.67320
		Equal var. not assumed			-.774	12.818	.453	-.36536	.47189	-1.38629	.65557

Table 4.19: Results of independent-sample T test for the diameter at 1mm between the younger and older age groups within each sex

Lateral and Medial Lengths Method

No published sectioning points were provided in the literature on the lengths of the lateral and medial walls of the internal acoustic canal, thus, predictive values for sex using these lengths could not be determined from previous research studies. Instead, the measurements for the lateral and medial walls were organized into frequency tables (Tables 4.20-4.23) to compare the distributions of the lengths between the sexes with those distributions published by Papangelou (1975).

TABLE 4.20 Distribution of Lateral Triangular Length versus Papangelou (1975)

Lateral Triangular Length								
	CT Sample		Papangelou (1975)		CT Sample		Papangelou (1975)	
mm	# of Males	Freq. (%)	# of Males	Freq. (%)	# of Females	Freq. (%)	# of Females	Freq. (%)
10	0	0	1	0.65	0	0	0	0
11	1	2.50	2	1.31	0	0	4	4.44
12	2	5.00	8	5.26	1	6.70	11	12.23
13	3	7.50	16	10.52	0	0	19	21.11
14	7	17.50	19	12.51	5	33.30	16	17.78
15	12	30.00	36	23.68	1	6.70	16	17.78
16	5	12.50	34	22.38	7	46.70	13	14.44
17	6	15.00	22	14.49	1	6.70	9	10.00
18	2	5.00	8	5.26	0	0	1	1.11
19	2	5.00	6	3.94	0	0	1	1.11
Total	40		152		15		90	

Table 4.20: Distribution of male and female left lateral lengths using the triangular length method compared to the distributions published by Papangelou (1975).

TABLE 4.21 Distribution of Medial Triangular Length versus Papangelou (1975)

Medial Triangular Length								
	CT Sample		Papangelou (1975)		CT Sample		Papangelou (1975)	
mm	# of Males	Freq. (%)	# of Males	Freq. (%)	# of Females	Freq. (%)	# of Females	Freq. (%)
6	0	0	2	1.31	0	0	1	1.11
7	2	5.00	12	7.9	0	0	4	4.44
8	6	15.00	39	25.66	1	6.70	24	26.67
9	11	27.50	33	21.71	6	40.00	24	26.67
10	10	25.00	35	23.05	3	20.00	28	31.12
11	6	15.00	20	13.15	4	26.70	5	5.55
12	4	10.00	6	3.94	1	6.70	2	2.22
13	1	2.50	4	2.63	0	0	2	2.22
14	0	0	1	0.65	0	0	0	0
Total	40		152		15		90	

Table 4.21: Distribution of male and female left medial lengths using the triangular length method compared to the distributions published by Papangelou (1975).

TABLE 4.22 Distribution of Lateral Polyline Length versus Papangelou (1975)

Lateral Polyline Length								
	CT Sample		Papangelou (1975)		CT Sample		Papangelou (1975)	
mm	# of Males	Freq. (%)	# of Males	Freq. (%)	# of Females	Freq. (%)	# of Females	Freq. (%)
10	0	0	1	0.65	0	0	0	0
11	0	0	2	1.31	0	0	4	4.44
12	1	2.50	8	5.26	0	0	11	12.23
13	2	5.00	16	10.52	1	6.70	19	21.11
14	4	10.00	19	12.51	1	6.70	16	17.78
15	5	12.50	36	23.68	3	20.00	16	17.78
16	14	35.00	34	22.38	4	26.70	13	14.44
17	3	7.50	22	14.49	5	33.30	9	10.00
18	4	10.00	8	5.26	1	6.70	1	1.11
19	5	12.50	6	3.94	0	0	1	1.11
20	2	5.00	0	0	0	0	0	0
Total	40		152		15		90	

Table 4.22: Distribution of male and female left lateral lengths using the polyline length method compared to the distributions published by Papangelou (1975)

TABLE 4.23 Distribution of Medial Polyline Length versus Papangelou (1975)

Medial Polyline Length								
	CT Sample		Papangelou (1975)		CT Sample		Papangelou (1975)	
mm	# of Males	Freq. (%)	# of Males	Freq. (%)	# of Females	Freq. (%)	# of Females	Freq. (%)
6	0	0	2	1.31	0	0	1	1.11
7	0	0	12	7.9	0	0	4	4.44
8	0	0	39	25.66	0	0	24	26.67
9	1	2.50	33	21.71	0	0	24	26.67
10	8	20.00	35	23.05	2	13.30	28	31.12
11	5	12.50	20	13.15	4	26.70	5	5.55
12	10	25.00	6	3.94	4	26.70	2	2.22
13	10	25.00	4	2.63	1	6.70	2	2.22
14	4	10.00	1	0.65	4	26.70	0	0
15	1	2.50	0	0	0	0	0	0
16	1	2.50	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
Total	40		152		15		90	

Table 4.23: Distribution of male and female left medial lengths using the polyline length method compared to the distributions published by Papangelou (1975)

A paired-samples t-test determined that although there were significant correlations between the triangular and polyline methods for the lateral (correlation = 0.966; $p < 0.001$) and medial (correlation: 0.925; $p < 0.001$) lengths, there was a statistically significant difference when comparing the means of the lateral triangular length and lateral polyline length ($p < 0.001$), and the medial triangular length and medial polyline length ($p < 0.001$). A paired-samples t test spit by sex also indicated statistically significant differences for the same measures (Table 4.24). Therefore, independent-samples t tests were run for both the triangular and polyline methods to examine any possible differences between the male and female means for the lateral and medial lengths (Table 4.25). For the triangular method, no statistically significant sex differences were found for the length of the lateral ($p = 0.784$) or medial ($p = 0.627$) walls of the internal acoustic canal. The t test results for the polyline method also indicated that sex differences were statistically insignificant for the lateral ($p = 0.611$) and medial ($p = 0.710$) lengths.

TABLE 4.24 Comparison of the Triangular Lengths to the Polyline Lengths

Paired Samples Correlations

True Sex			N	Correlation	Sig.
Male	Pair 1	Lateral Triangular Length & Lateral Polyline Length	41	.971	.000
	Pair 2	Medial Triangular Length & Medial Polyline Length	41	.916	.000
Female	Pair 1	Lateral Triangular Length & Lateral Polyline Length	14	.934	.000
	Pair 2	Medial Triangular Length & Medial Polyline Length	14	.966	.000

Paired Samples Test

True Sex			Paired Differences					t	df	Sig. (2-tailed)
						95% Confidence Interval of the Difference				
			Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Male	Pair 1	Lat Tri Length – Lat Poly Length	-1.14171	.46898	.07324	-1.28974	-.99368	-15.588	40	.000
	Pair 2	Med Tri Length - MedPoly Length	-2.31659	.68528	.10702	-2.53289	-2.10029	-21.646	40	.000
Female	Pair 1	Lat Tri Length – Lat Poly Length	-1.03857	.47126	.12595	-1.31067	-.76647	-8.246	13	.000
	Pair 2	Med Tri Length – Med Poly Length	-2.33000	.48122	.12861	-2.60785	-2.05215	-18.117	13	.000

Table 4.24: Results of the paired-samples T test for the lengths of the lateral and medial canal walls using the triangular and polyline methods

TABLE 4.25 Descriptive Statistics for the Triangular and Polyline Lengths

Descriptive Statistics						
True Sex		N	Minimum	Maximum	Mean	Std. Deviation
Male	Lateral Triangular Length	41	11.46	18.82	15.0676	1.81584
	Medial Triangular Length	41	6.98	13.27	9.6537	1.39909
	Lateral Polyline Length	41	12.01	20.18	16.2093	1.94671
	Medial Polyline Length	41	9.46	16.43	11.9702	1.67463
	Valid N (listwise)	41				
Female	Lateral Triangular Length	14	12.38	16.57	15.1021	1.17164
	Medial Triangular Length	14	8.41	11.89	9.9393	1.08247
	Lateral Polyline Length	14	13.11	17.76	16.1407	1.30802
	Medial Polyline Length	14	10.10	14.49	12.2693	1.43534
	Valid N (listwise)	14				

Table 4.25: Results of the descriptive statistics illustrating the means for the lateral and medial lengths using the triangular and polyline methods

The relationship between the length of the canal walls and age was examined for the lateral and medial lengths for both the triangular and polyline methods. No significant correlations were found for the triangular method (lateral length $p = 0.758$; medial length $p = 0.612$) or the polyline method (lateral length $p = 0.879$; medial length $p = 0.542$) when the sexes were combined. There were also no significant correlations between length and age in females or males for either method when each group was considered independently.

Sex Predictive Value for the Metric Measurements of the Internal Acoustic Canal

No statistically significant sex differences were found between males and females for the lateral angle, diameter measurements, or the length measurements of the internal acoustic canal. Since no sex differences were found during the initial statistical analysis of the data, the application of logistic regression analyses for determining the sex predictive value of these specific traits of the petrous portion was superfluous. The overall allocation accuracies for each of the measurements when considered alone, as well as for the combination of various measurements ranged from 70.9-74.5%. The predictive value for males ranged from 95-100% for each of the variables when considered alone, or in various combinations. For females, however, the predictive value for the individual and combination measurements was extremely low ranging from 0-26.7%. The lateral angle, and the combinations of: 1) the lateral angle and all three diameter measurements; 2) lateral angle and the diameter at 2mm; 3) the diameter at the opening and the diameter at 2mm; and 4) all three diameter measurements combined, had predictive values of 6.7% for females whereas all other measurements had predictive values of 0%. When all of the measurements obtained from this sample were combined (lateral angle, diameter at the opening, 1mm, and 2mm, lateral and medial triangular lengths, lateral and medial polyline lengths), the overall allocation accuracy reached 74.5%; however, the predictive value for females was only 26.7%.

The data collected for the current study revealed several surprising, and somewhat disappointing, results when compared against those published previously which illustrated significant sexual dimorphism in the internal acoustic canal of the petrous portion (Norén et al., 2005; Lynnerup et al., 2006; Akansel et al., 2008). Several potential reasons for the results achieved here will be discussed in the next chapter, along with some of the challenges faced and methodological decisions made during the research process.

Chapter V: Discussion and Conclusions

The primary goal of this research was to validate and refine three methods for sexing the internal acoustic canal, located in the petrous portion of the temporal bone. Overall, the results indicate that there is no statistically significant difference between males and females for the three tested methods. These findings are inconsistent with the previous literature (Akansel et al., 2008; Graw et al., 2005; Lynnerup et al., 2006; Norén et al., 2005), and several possible explanations for these results are addressed.

Methodological Challenges

MIMICS medical imaging software was used in the current study for the metric analysis of the internal acoustic canal and provides a range of tools that allows for both the two-dimensional image analysis and three-dimensional reconstruction of the petrous portion. The methods of analysis for the current study used only the two-dimensional CT images to obtain the various measurements of the internal acoustic canal for several reasons. The original cadaveric studies of the lateral angle (Graw et al., 2005; Norén et al., 2005; Wahl, 1981) reduced the three-dimensional negative cast to two-dimensions in order to measure the angle of the cast more precisely. In order to replicate the effect of the longitudinal bisection of a negative cast the lateral angle sizes were obtained from the axial 2-D CT images following Akansel et al. (2008).

Due to the nature of this analysis, the diameter method proposed by Lynnerup and colleagues (2006) could not be directly reproduced, but was modified to work within the measurement capabilities of MIMICS. This modified approach measured the horizontal diameter from the edge of the lateral wall to the edge of the medial wall at three different points within the internal acoustic canal. Three-dimensional reconstructions of the temporal bone were not used for the diameter method since the reconstructed model would have required bisection in the axial plane, along the posterior surface of the petrous portion, in order to properly delineate the bony lateral and medial borders of the canal. This was more quickly and easily visualized by simply using the same 2-D CT image used for the lateral angle method rather than using a bisected three-dimensional model of the petrous portion. Finally, for similar reasons, the lateral and medial length measurements were also applied directly onto the 2-D CT images.

Bilateral Differences and Intra-Observer Error

The first step of the analysis was to evaluate the previously documented lack of difference between the canal measurements of the left and right petrous bones, as well as to assess intra-observer variation. The results indicated that bilateral variation in the measurements of the internal acoustic canal was negligible, making the left and right petrous portions interchangeable for each of the three methods.

The next step in the statistical analysis was to determine whether the image-based measurements developed for this study could be reliably reproduced. Several weeks after the data collection process, a paired-sample statistical analysis indicated that the measurements collected using the methods of the current study could be reproduced reliably by the same researcher for the 10 individuals randomly selected for re-measurement.

The Lateral Angle Method

The first objective of this study was to evaluate the lateral angle method for determining the sex of human skeletal remains. The same sectioning point of 45° reported by Albrecht (1997), Graw (2001), and Norén et al. (2005) was applied to the current data to determine if the sex predictive value reached the same accuracy as the previous methods for the sample used for this study. The results were disappointing and yielded an accuracy level of only 53%, well below the minimum standard of 80% reported by Williams and Rogers (2006) as the standard for identifying high quality cranial traits for the determination of sex. In fact, a similar accuracy can be achieved without osteological experience by simply guessing as to the correct sex since there are only two choices: male or female (i.e. there is already a 50% chance that the assignment of sex is correct).

When this result is considered along with previously reported accuracies for sexing the lateral angle, it is clear that the overall research findings are inconsistent. Whereas Norén and colleagues (2005) demonstrated that the lateral angle reliably predicts the sex of skeletal remains, Graw et al. (2005) reported a much lower accuracy. The inconsistency in the previous results, along with the current findings, supports the conclusion that there is a certain degree of human variation in lateral angle size within and between different populations, as well as within and between the sexes.

As a result of the varying accuracies reported for different skeletal samples, it was initially assumed that the low predictive value of the 45° sectioning point in this study could be attributed to population specificity in the sectioning point value; however, upon further statistical investigation of the data, it was revealed that no sectioning point could be determined which could satisfactorily differentiate between the sexes. This was the direct result of both the relatively large range of measurements within both sexes, and the considerable overlap of lateral angle CT measurements between the sexes (males: 32-60˚; females: 39-65˚). However, measurements of 40˚ and lesser were found to be 93.3% specific for males (14 out of 15 females were excluded correctly). A single individual, a female, had a lateral angle value above 65˚; however this was not sufficient evidence to make any valid conclusions, thus, no lateral angle value that was highly specific for females could be identified for the current sample. These results are consistent with findings in similar studies of the lateral angle (Akansel et al., 2008). Using the same 2D-CT measurements on a CT sample from 95 patients (49 females, 46 males), Akansel et al.'s (2008) results also revealed a significant overlap in the ranges of measurements to a degree that did not allow for the determination of a sectioning point that adequately separated the sexes (males: 30-60˚; females: 30-68˚). It was found, however, that measurements of 35˚ and lesser were 93.6% specific for males, whereas measurements of 60˚ and greater were 97.7% specific for females. Similarly, in a cadaveric study, Graw et al. (2005), who also did not provide a sectioning point, also reported that a lateral angle size below 40˚ spoke in favour of male, while angles above 65˚ spoke in favour of females when analyzing the lateral angle from 410 forensically modern temporal bones. Therefore, the results from the current data, which found that a lateral angle of 40˚ or less is specific to males, suggest that some degree of sexual dimorphism in the lateral angle may exist, but the composition and distribution of the sample used here was not adequate to detect the small difference between male and female lateral angle size at a statistical level.

Perhaps the most surprising result from the analyses of the current data was the absence of a statistically significant difference between the male and female mean values. The mean values for the lateral angle of the internal acoustic canal were $46.7 \pm 6.2^{\circ}$ for females and $44.3 \pm 7.1^{\circ}$ for males. Although the mean lateral angle value was greater in females than in males, the difference did not reach statistical significance. This may have been due to the small number of females used in this study. The small sample size (40 males, 15 females), particularly with reference to the female sub-sample, may have precluded the ability to more accurately interpret the larger populational pattern of sex differences in the lateral angle. Akansel and colleagues (2008) encountered a similar issue when analyzing lateral angle sex differences in a small sub-sample of sub-adult subjects (17 males, 5 females). The mean lateral angle in females was $51.4 \pm 10.7^{\circ}$ and in males was $44.2 \pm 8.3^{\circ}$; however, the difference was not significant statistically despite the large numerical difference between the male and female means. This lack of statistical significance was also attributed to the inadequate sample of sub-adults as well as the small number of female subjects.

An additional analysis using a sub-sample of an equal number of males and females (15 females, 15 randomly selected males) also indicated that no statistically significant sex differences were found for the lateral angle. The overall accuracy for this method dropped from 74.5% from the original sample ($n = 55$) to 63.3% in the sub-sample ($n = 30$); however, the predictive accuracies for males and females evened out to 66.7% and 60%, respectively. This eliminated the male bias in the predictive accuracies observed in the original sample (males: 100%, females: 6.7%), which was clearly a product of sample composition. Although no statistical significance was found, and the accuracies did not meet the minimum standard for high quality cranial traits, these results do indicate that a weak sexual dimorphism in the lateral angle exists, but that the use of this trait in anthropological applications is limited, and is not as practical as using other highly dimorphic skeletal elements such as the pelvis. It is recommended that future research using CT scan data to analyze the lateral angle use a larger sample of individuals with a relatively equal distribution of the sexes to determine, with greater confidence, whether this skeletal trait is useful for sex determination.

The inconsistency between the statistical results from the current study and those previously published on the lateral angle may also be attributed to differences in methodologies. The casting method obtains the lateral angle measurements from the negative air space of the internal acoustic canal by placing the bisected cast onto a protractor with the base area considered as the horizontal aspect of the angle. The measurement is then obtained by estimating the angle of the cast based on its position on the protractor to the nearest 5° increment (Norén et al., 2005). This method of estimation may have affected the precision and accuracy of the lateral angle measurements.

In addition, Norén and colleagues (2005) have stated that the cast material must reach the distal part of the internal acoustic canal where the facial nerve departs from the vestibulocochlear nerve; otherwise, the cast may be too short for reliable angle measurement. It is possible that, due to the angled shape and small diameter of the canal, a complete replica including the most distal point of the apex is difficult to reproduce. The presence of a bony clip along the medial edge of the canal also results in a narrowing of the replica at the opening, which can make the successful removal of a complete cast extremely difficult. It is important to note that this bony clip is more frequently observed and more pronounced in females and, if a complete cast is not achieved, the canal may falsely appear steeper, resulting in a much larger, and potentially artificial, sex difference in lateral angle size (Graw et al., 2005). In fact, Graw et al. (2005) claim that Wahl (1981) was unable to achieve a complete replica of the canal for either sex and, as a result, observed larger angles for both males and females. It is for these reasons that a CT method was chosen to be tested for use in place of the traditional casting method.

The CT method used here measures the lateral angle directly off of the bone and the entirety of the lateral wall from the canal opening to the apex using a 2-dimensional image of the internal acoustic canal. This method obviates the potential measurement precision issues related to incomplete casting and inflated angle sizes. The largest difference between the two methods is that rather than estimating the angle to the nearest 5° increment using a protractor, the measurement tools provided by MIMICS obtains the angle directly from the lines placed onto the image to 2 decimal places. It is possible that this difference in the methodologies had an effect on the size of the lateral angle between males and females, and may explain the differences in sex determination accuracy and statistical significance between the current research and the previously published literature on the lateral angle method.

No significant linear correlation was found between age and the lateral angle, which is consistent with the findings of Akansel et al. (2008) and Graw et al. (2005). Norén et al. (2005) does not provide any results for the relationship between the internal acoustic canal and age, so no comparison of results with this particular publication could be made. The individuals in this study were separated into two age groups, a younger group (<50) and an older group (50+), based on previous findings that age-dependencies relating to the petrous portion were found from 50 years of age onwards (Graw et al., 2005; Wahl and Graw, 2001). The lateral angle between the age group up to 49 years and the group 50 years and older yielded a statistically significant difference for the entire group, but not for males or females when they were analyzed separately. When closely scrutinizing the results of this analysis, it was determined that the lateral angle size was approximately 4° larger in the sub-sample of individuals 50 years and older for both males and females. This finding suggests that although no linear correlation with age was present that the size of the lateral angle significantly increases with the progression of age.

The mean age difference between males and females in the current sample was not statistically significant; however, future investigations should be mindful of the age distribution of the sample being used as it may affect the overall results of the statistical analysis. Based on the current results, it is possible that a sample composed only of younger males and older females may yield a statistically significant difference between the sexes as a result of the effects of age on the size of the lateral angle, rather than a true representation of populational sex differences.

Although it was disappointing to find that the lateral angle method yielded no statistical significance between the sexes, it is interesting to note that the mean values, ranges, and standard deviations that were observed in this study are similar to those reported from the cadaveric study of Norén et al. (2005), as well as the CT study of Akansel et al. (2008) (Table 5.1). This suggests that computerized tomographic measurements may serve as a substitute for direct anatomic measurements in human osteological research.

TABLE 5.1 Comparison of Lateral Angle Means, Ranges, and Standard Deviations

Lateral Angle	Current Data	Norén et al. (2005)	Akansel et al. (2008)
Mean -Males	44.3	39.3	41.6
Mean- Females	46.7	48.2	45.5
Range - Males	32-60	25-65	30-60
Range - Females	39-65	35-65	30-68
St. Dev - Males	7.1	6.4	6.7
St. Dev - Females	6.2	6.8	7.1

Table 5.1: Comparison of lateral angle means, ranges, and standard deviations from the present study compared with previously published results

The Diameter Method

The second objective of this research was to evaluate the diameter of the opening of the internal acoustic canal for sex determination of skeletal remains using the petrous portion of the temporal bone. The previous method of inserting a circular object into an oblique opening in order to approximate the diameter will result in a less precise measurement. Lynnerup and colleagues (2006) have taken note of this issue, and have suggested that more advanced morphometric analyses using image-based measurements are used in future investigations. It was the goal of this study to apply such an image-based analysis using CT images of the internal acoustic canal to achieve more precise measurements of the diameter. It should be noted that the current CT method still requires some modification as the data used in this analysis was limited by the 2mm slice thickness, low spatial resolution, and a loss of contrast in the 2-D CT images. It is possible that the low resolution and poor edge definition of the bone may have reduced the actual size and shape of the canal, which may have affected the accuracy of the diameter measurements taken from the image. It is recommended that the future use of CT images for measuring the internal acoustic canal test the accuracy of the diameter measurements using various slice thicknesses, contrasts, and resolutions.

The current study measured from the lateral to medial walls by placing measurement points along the bony edges of the canal, rather than inserting objects of various sizes into the canal in order to estimate the diameter. As a result of this difference in methodology, the values obtained for the diameter were much higher than those reported in the previous research (Lynnerup et al., 2006). In addition, the drill end method was also limited by the size of the vertical diameter, which may also be an explanation for the larger values obtained in the current study, as only the horizontal diameter was measured. Even if the opening was significantly wider along the horizontal axis, the size of the drill end that can be inserted remains dependent upon the size of the opening along the vertical axis. It is recommended for future investigations that both the horizontal and vertical diameter be obtained using CT data and image-based measurements in order to examine if sex differences exist in the ratio of the two measurements. In the present study, the vertical diameter was not measured from the CT images because of the effect of CT scanner anisotropy and the low resolution of the images in general.

As has been discussed in the previous Results chapter (pg. 92), sex could not be accurately predicted using the sectioning points provided by Lynnerup et al. (2006). Nor could these previously published sectioning points be adequately tested for validity in determining sex as a result of the larger diameter values obtained in the present study. Although a direct validation of Lynnerup et al.'s (2006) results was not possible using the current data, the finding that there is sexual dimorphism in the diameter of the internal acoustic canal could be tested. Thus, frequency tables were constructed to analyze any potential differences in the distribution of each of the three diameter measurements between the sexes. In analyzing the frequency tables, it was observed that the diameter of the opening revealed a similar distribution of measurements between males and females; however, the diameter at 1mm and the diameter at 2mm appear to have slightly different distributions, with males tending to have larger diameter values than females. These observations are also supported by the differences in the male and female mean values for each of the diameter measurements. The mean difference for the diameter taken at the canal opening was only 0.03mm, whereas the mean differences for the 1mm and 2mm diameters were 0.20mm and 0.36mm respectively (Table 4.12 in Results pg. 94). The results for the mean difference in diameter measurements between the sexes in this study were consistent with Lynnerup et al.'s (2006) finding that the mean diameter values between males and females differed by 0.30mm. This may support the earlier suggestion that the drill end method likely measured the diameter inside of the canal, rather than the actual opening.

Despite the consistency in the mean value differences between the current study and Lynnerup et al.'s (2006) research, the results of the statistical tests conducted herein were disappointing, revealing no statistically significant differences between the male and female means for any of the three diameter measurements. This is an interesting finding as the difference in the mean value of the diameter at 2mm for the present sample was slightly larger (0.36mm) than the difference found by Lynnerup et al. (2006) (0.30mm). Like the lateral angle, the lack of statistical significance in the present study may be related to the composition and distribution of the sample that was analyzed. An additional explanation may be that sexual dimorphism in the diameter of the internal acoustic canal is extremely slight and could not be detected in the statistical analysis.

Although Lynnerup and colleagues (2006) reported a statistically significant difference between the means of the male and female diameters, this difference was extremely small (0.30mm) and the predictive value for correct sexing was only 70%, falling below the minimum standard (80%) for high quality skeletal traits. Also, when Lynnerup et al.'s (2006) predicted sex was tabulated against known sex using their predetermined sectioning points, it was reported that Cohen's kappa statistic revealed a weak agreement between predicted and known sex. This was attributed to the low predictive value for females which was found to be only 38%, whereas the predictive value for males was 91% (Lynnerup et al., 2006). Overall, Lynnerup et al.'s (2006) method carries a very low predictive value for correct sexing, and presents extremely poor results for females. An interesting finding to note was that the data from the current study indicated that the diameter method carries a similar allocation accuracy of 70.9% when all three diameter measurements are combined, with a predictive accuracy of 95% for males, and only 6.7% for females.

In the re-analysis of the data using the sub-sample of 15 males and 15 females, the allocation accuracy for the three diameter measures dropped to 63.3%, and the predictive accuracies for males and females levelled off at 66.7% and 60%, respectively. Similarly to the results for the lateral angle, this suggests that the allocation accuracies found in the original data set were a product of a male biased sample and that sexual dimorphism may be detected if a larger sample composed of an equal number of males and females is used. These findings indicate that the inability to reach statistical significance using the current data may be related to the limited number of females available for the present study, and/or weak sexual dimorphism in diameter size. Further CT research which can adequately obtain both the vertical and horizontal diameters may allow for a better understanding of the degree of sexual dimorphism of the diameter of the internal acoustic canal.

In an analysis of the relationship between the diameter and age, a positive, but weak ($r = 0.582$) linear correlation reached statistical significance only in females, and only at the measurement of the diameter at 1mm. This suggests that there may be an age-related change in the size of the diameter in females; however, it is interesting to note that no statistically significant correlations with age were found at the diameter of the opening, or the diameter at 2mm, both of which are found on either side of the location for the 1mm measurement. The small number of female subjects used in this study may preclude a proper interpretation of age-related changes in this particular parameter. Lynnerup et al. (2006) did not report on the effect of age on the size of the diameter, and Papangelou (1975) reported that no correlation was found between age and the length of the diameter. However, in the present study, like the lateral angle, a statistically significant difference was found for the diameter of the canal opening when the younger (<50) and older (50+) sub-samples were compared. In addition, statistical significance was achieved between the younger and older groups only in males for the diameter of the opening, as well as the diameter at 1mm when the sexes were analyzed separately.

Unlike the increase observed in the lateral angle, the diameter measurements significantly decreased with age, specifically in males. Future research on the diameter of the internal acoustic canal need be aware of these age related changes in the diameter to ensure that the composition of the sample being used is equal in terms of the distribution of age. A skewed sample, particularly with reference to the age of males, may prevent an accurate representation of the distribution and/or sexual dimorphism of the diameter as it applies to the larger population.

The Lateral and Medial Lengths Method

The third objective of the present study was to examine the length of the lateral and medial walls of the internal acoustic canal for sex differences. The triangular method most closely approximated the method used by Papangelou (1972), and the polyline method was developed in an attempt to enhance the precision of the length measurements to determine if this had any effect on sex determination accuracy. The length distributions produced using the current data were consistent with the published results (Papangelou, 1975), and support the finding that the distributions of the lateral and medial lengths are similar between males and females. As was expected, the most comparable results were achieved using the triangular method since it most closely approximated the methods of the previous research (Papangelou, 1975). This method resulted in all of the length measurements for both sexes falling within the same ranges as those reported by Papangelou (1975). In addition, the frequencies for the lateral and medial triangular lengths were also similar to previous results, particularly for the male sub-sample. For females, however, although the ranges for the lateral and medial triangular length measurements were consistent with those published by Papangelou (1975), the frequencies appear to be different. This difference can be attributed to the small sub-sample of females analyzed in the current study.

The results of the polyline method were similar to those of the triangular method; however, as a result of the increased precision in measurement, the values for the lateral and medial lengths were larger, resulting in distributions with larger ranges. The frequencies for males and females were also shifted to higher length values, resulting in slight inconsistencies when compared to Papangelou's (1975) results. This shift is reflected in the results of the paired samples t test which indicated that there were significant differences in the length measurements between the triangular and polyline methods. The length of the medial wall was particularly affected by the technical differences between these two methods. Although the canal is curved, or angled, in nature, the lateral wall tends to travel into the petrous bone in a fairly linear fashion. On the other hand, the concave aspect of the medial wall, which forms the bony clip, is circumvented by a straight line and not included in the medial length when the triangular method is used. This explains the larger increase in values for the medial polyline lengths in both sexes. Despite the larger length values, the distributions of the lateral and medial polyline lengths in the current study are similar between males and females, again supporting the findings published by Papangelou (1975).

Based on the observation that the distributions of the lateral and medial lengths were similar between males and females, Papangelou (1975) concluded that the shape of the internal acoustic canal was not related to sex. In the present study, it was anticipated that sex differences may be found in the length measurements when statistical tests were applied to the data, since Papangelou (1975) did not support her conclusions with statistical results. Unfortunately, statistical significance was not observed for any of the length measures when the mean differences between males and females were compared. In addition, although the polyline method may have improved the precision of the length measurements, it had no effect on the accuracy of sex determination since there were no statistically significant sex differences for the lateral and medial lengths. Finally, no correlation was found between age and the lateral and medial lengths of the internal acoustic canal. These results validate the conclusions reached by Papangelou (1975), in that the length of the internal acoustic canal remains unchanged with age, and is not a sexually dimorphic characteristic of the cranium.

Logistic Regression Analysis

The statistical analyses of the lateral angle, diameter of the opening, and lateral and medial length measurements all revealed no statistically significant sex differences, suggesting that there is no sexual dimorphism in the internal acoustic canal in this specific sample of individuals. The final step in this research was to model sexual dimorphism in the study sample directly using logistic regression analysis. Both single and multiple variable logistic regression analyses were run to examine variations within the present sample. Since statistical significance was not reached between males and females for any of the internal acoustic canal measurements, the allocation accuracies of the logistic models applied to the current data used to develop the models were low and there were significant biases toward the male sex for all of the measurements. When all of the measurements for each of the cranial traits were combined, the allocation accuracy was only 74.5%, with a predictive value of 92.5% for males and 26.7% for females.

The overall allocation accuracy for the re-tested sub-sample (15 males, 15 females), however, increased to 86.7% when all of the cranial measurements were combined, and the predictive accuracies for males and females reached the same level at 86.7%. Although no statistical significance was found for any of the cranial traits in the sub-sample, the high allocation accuracies for both males and females suggest that there may be some promising results for future investigations of sexual dimorphism in the internal acoustic canal.

Implications and Limitations

Traditional osteometric measurements of human skeletal remains are typically made using simple rulers, calipers and goniometers; however, two- and three-dimensional imaging methods have also been found to be both valid and reliable enough to be applied in the same ways as traditional physical analyses (Hildebolt and Vannier, 1988; Weber et al., 2001). The cadaveric methods, including the negative cast (Norén et al., 2005; Papangelou, 1972, 1975) and drill end methods (Lynnerup et al., 2006), were refined in the present study through the application of image-based measurements directly onto the bony surface of the internal acoustic canal using a forensically modern sample of CT scans of the skull.

Several of the major limitations of this research were directly related to the adequacy of the CT data that was used to analyze the internal acoustic canal. First, the canal is an extremely small structure within the skull; therefore, there were some concerns regarding the effects of partial volume artifacts as a result of the 2mm slice thickness on the accuracy of the measurements required for this study. The CT value assigned to each pixel in an image is a representation of the average x-ray attenuation properties of the volume of tissue in the corresponding 3-D voxel (same in-plane dimensions as the pixel, but with the slice thickness dimension). Because the diameter of the canal is, on average, only two to three times larger than the slice thickness used for the acquisition of the CT data, many of the voxels that correspond to the 2-D pixels in the images of the canal contained a mixture of tissue types, specifically bone and soft tissue. If a volume of tissue, or 3-D voxel, contains both a low density material, such as the soft nerve tissue within the internal acoustic canal, as well as a high density material, such as the surrounding petrous bone, the two densities are averaged to create a CT value that is not representative of either tissue type (Bushberg et al., 2002). As a result, there is a subsequent blurring of the sharp edges that delineate these low and high density materials and an overall loss in spatial resolution occurs. This process is known as a partial volume effect, and contributed to the blurring of the bony edges of the internal acoustic canal, making it difficult to distinguish between the negative space of the canal and the borders of the lateral and medial walls. Figure 5.1 illustrates the increased blurring that occurs along the canal walls when slice thicknesses of 0.5mm, 1mm, and 2mm are compared.

FIGURE 5.1 Comparison of Resolution at Slice Thicknesses of 0.5mm, 1mm, and 2mm

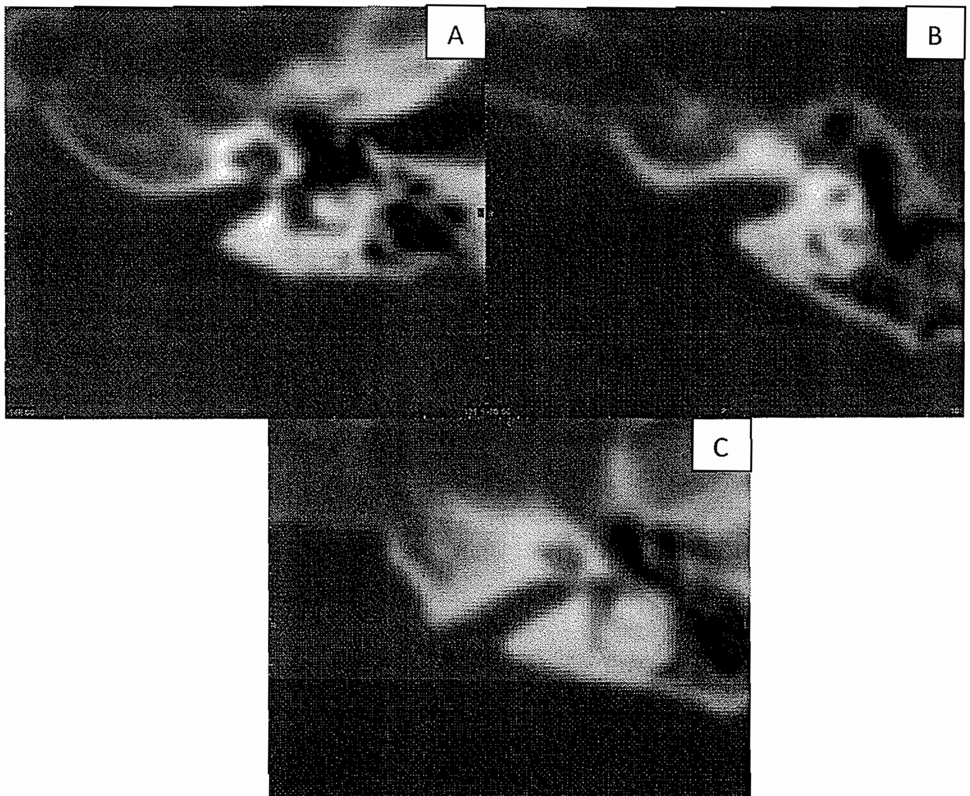

Figure 5.1: "A" illustrates the resolution at a slice thickness of 0.5mm. "B" demonstrates the resolution at 1mm, and "C" represents the resolution at a slice thickness of 2mm. (H20s; -1024-1650 HU)

In addition to the issues with the large slice thickness, relative to the size of the internal acoustic canal, the second problem with these CT data was the reconstruction filter used during the post-processing of the 2-D images. The reconstruction filter was set to an H20 kernel, which is a standard smoothing filter that is traditionally used for soft tissue reconstruction. This filter is used to achieve high contrast resolution at the cost of high spatial resolution and therefore produces images with reduced image noise (smoothing effect) but low spatial resolution. Thus, the ability to distinguish small objects with increased spatial frequencies is significantly reduced (Bushberg et al., 2002).

This was a major limitation for the study conducted here as the internal acoustic canal is a very small skeletal structure which was not resolved with the necessary detail on the CT images provided. As a result of the reconstruction kernel and the low spatial resolution of these data, the canal appeared significantly blurred, and delineating the edges of the canal walls for measurement placement was met with extreme difficulty. Although the intra-observer error results indicated that there was adequate measurement precision (reproducibility), the accuracy of the measurements would have been limited by the blurring effects of both the smoothing kernel and slice thickness. The effects of these data limitations on the accuracy of the measurements may have contributed to the finding that there were no statistically significant sex differences in the measures analyzed.

Finally, the third limitation of these data was the use of post-mortem CT scans, as the control over the accurate positioning of the patient's head during the scanning process was limited. For many of the individual CT scans, the head tended to tilt to the side, and the captured slices were no longer parallel to the axial plane. When the CT slices were not parallel with the axial plane there was a distortion in the size and shape of the canal and accurate measurements could not be obtained. Therefore, in an attempt to overcome this issue, a protocol for the selection of the appropriate CT slice from which to obtain measurements of the canal was developed; however, this resulted in a significant reduction in the sample size, which also likely played a role in the disappointing results of this research.

Overall, it should be noted that, as a result of the 2mm slice thickness, low spatial resolution, and head positioning, the data set provided for the current study was likely not sufficient for an accurate analysis of sexual dimorphism in the internal acoustic canal.

These specific data are excellent for the analysis of large skeletal structures and/or soft tissues, but it is recommended that future research projects focused on small skeletal structures, such as those of the inner ear, use CT data that is reconstructed using a much sharper filter with a decreased slice thickness. A sharper reconstruction kernel will increase the spatial resolution, allowing for smaller high frequency details to be clearly resolved with improved edge definition, and thinner slices will decrease the effects of partial volume artifacts and increase the resolution of the saggital and coronal planes. Thus, it is suggested that high resolution clinical CT scans of the temporal bone be used as these data are specifically reconstructed for the purposes of examining the structures of the inner ear. In addition, a future research project which compares the accuracy of measurements of the internal acoustic canal using a range of slice thicknesses, reconstruction kernels, and CT scanners (micro-CT versus traditional CT) will aid in better understanding the limitations of CT methods, and will better determine the potential use of the internal acoustic canal for determining sex.

Differences in methodologies, and imaging limitations resulted in some discrepancies in values when comparing past and present results, particularly for the diameter method. It is recommended that future investigations combine both methods of analysis to evaluate the true level of disagreement between manual and image-based measurement methods. Overall, however, despite the insufficiency of the CT scan data, many of the descriptive statistical findings from the current data were consistent with the previous research. These findings support the results reported by Hildebolt and Vannier (1988) and Weber et al. (2001) that image-based measurements taken from 2-D CT images may serve as an alternative for direct anatomical measurement when the appropriate post-processing techniques are employed. These results may encourage anthropologists and archaeologists to collaborate with radiologists to further examine the potential of biomedical imaging in anthropological research.

The results of this study have shown that the observed metric aspects of the internal acoustic canal, which have previously shown to be reliable sex indicators, were not successful in sexing this CT sample. The means, mean differences, and range of measurements observed from the current data were relatively consistent with the previously published results (Akansel et al., 2008; Lynnerup et al., 2006; Norén et al., 2005; Papangelou, 1975); however, no statistically significant sex differences were found. As has been discussed (pg. 11-12), metric techniques for determining sex change in their applicability and accuracy when they are applied to skeletal material that is not derived from the reference populations from which the techniques were originally developed. Therefore, the poor results of this study may indicate that inter-population variations in anthropological characteristics could have also considerably affected the accuracy of sex assessment in this particular sample of individuals.

Although sexing from the skull is potentially reliable, a number of problems do arise as a result of inter-populational variation, particularly in homogenous, egalitarian populations that are weakly dimorphic (Mays and Cox, 2000). Sexual dimorphism in the skull is directly related to size differences wherein male skulls tend to be larger, and more robust than females; however, this is not a universal phenomenon as some populations are typically robust, and others typically gracile. In these populations, skulls of both sexes may appear to be male in a more robust population, or all female in a gracile population (Wienker, 1984). Such population differences generally restrict the crosspopulational application of metric techniques and lessen the accuracy of size-differential sexing (Rogers, 2005; Walsh-Haney, 1999). In the current study, when comparing the male and female means for the lateral angle to previous results the female mean fell within the same reported values published by Akansel et al. (2008) and Norén et al. (2005). The male mean, however, was slightly higher than the previously reported means (i.e. Akansel et al., 2008; Norén et al., 2005) and was slightly closer to values that are typical of females (Table 5.1). This finding, along with the lack of statistical significance in lateral angle size between the sexes, suggests that the sample used in this study represents a population with weak sexual dimorphism and less robusticity in the male skull. Similar results were also reported in a study that tested the applicability of sex determination methods in an Albanian skeletal sample, □urić et al. (2005) reported that the mean ratio of correctly sexing the crania was only 45.53% when applying methods which had previously been found to be reliable for accurately sexing the skull. These observations were the direct result of a weakly dimorphic population and, specifically, the less robust skulls of Albanian males, who displayed cranial traits generally considered characteristic of females. Finally, as a result of the range in accuracies reported for the lateral angle method, and the variation in the angle and size of the canal (Akansel et al., 2008; Graw et al., 2005; Norén et al., 2005), population differences in the degree of dimorphism in the skull, and particularly the cranial base, may explain the lack of statistical significance between the sexes in the current CT sample for the measurements of the internal acoustic canal.

Overall, the results from the current study were somewhat unexpected since significant sexual dimorphism was reported for the internal acoustic canal in several previous publications (Akansel et al., 2008; Lynnerup et al., 2006; Norén et al. 2005). The results for the lateral angle method were particularly disappointing since Norén et al. (2005) had previously achieved a significantly reliable level of accuracy using this method (83.2%). The lack of statistical significance between male and female diameter measurements was also unanticipated, but not overly surprising considering the low predictive values published by Lynnerup et al. (2006). In addition, the lack of sex differences in the lateral and medial lengths was not completely unforeseen since there was a significant overlap between males and females in the length distributions published by Papangelou (1975), and it had previously been stated that the shape of the canal was not dependent upon sex (Papangelou, 1975).

The present study had several limitations that may have affected the final results. First, any individuals who were scanned with considerable head tilt could not be included in the study as this resulted in a significantly warped, or distorted, image of the internal acoustic canal. These distorted images did not meet the protocol for selecting the necessary CT slice as outlined in the Methods chapter (pg. 70-71), resulting in a reduced sample size. The sample composition and distribution may have affected the ability to adequately test the degree of sexual dimorphism in the lateral angle, diameter, and lateral and medial lengths in this CT sample. Although the mean lateral angle value was greater in females than in males, and the male means for the diameter and length measurements were larger than the female means, the differences did not demonstrate statistical significance, most probably due to sample composition. It is recommended that later research on this skeletal element be done on a larger sample, with an equal number of males and females, and that future studies using CT scan data need to be mindful of the potential effects of head tilt on the accuracy of internal acoustic canal measurements. It is also suggested that CT data be obtained from several different populations in order to better understand the possible inter-population variation in the sexual dimorphism of the petrous portion of the temporal bone. Second, although intra-observer error testing indicated that each of the methods used for the current study can be reliably reproduced by the same researcher, inter-observer error testing was not performed; therefore, it is recommended that future research using these same methods include a second observer to attempt to reproduce the same results. This would provide an additional check on the comparability of the specific measurements between different researchers and would further illustrate the reproducibility of the methods. Finally, the 2mm thickness of the majority of the CT scans used for this research resulted in poor resolution particularly in the sagittal and coronal planes, preventing an accurate analysis of the vertical diameter of the internal acoustic canal. It is proposed that future investigations use CT scan data with reduced slice thickness and higher spatial resolution as this would theoretically allow for more precise measurements and a clearer visualization of anatomical landmarks on the CT images (Akansel et al., 2008).

CONCLUSIONS

In a detailed review of the sex determination literature for the petrous portion, Wahl and Graw (2001) have concluded that the reliability of this skeletal element for correctly assigning sex to human remains is satisfactory for archaeological examinations, but is of marginal importance in forensic assessment. The purpose of the present research was to determine the overall value of the internal acoustic canal, located in the petrous portion of the temporal bone, to accurately determine sex. Since several of the cadaveric studies (Lynnerup et al., 2005; Norén et al., 2005), and one CT study (Akansel et al., 2008) yielded promising results in sexing the petrous bone it was expected that these results could be reproduced using image-based analyses.

Overall, no statistically significant differences related to sex were found for any of the three characteristics of the internal acoustic canal within the petrous portion of the temporal bone. In addition, it is possible that there are some age-related factors that influence the size and shape of the canal, which needs to be kept in mind for future investigations of the sexual dimorphism in the petrous portion. The inconsistencies in the results of the present study and those results of the previously published research (Akansel et al., 2008; Lynnerup et al., 2006; Norén et al., 2005), with particular reference to sex differences, can be attributed to several factors including: methodological differences and imaging limitations, inter-populational variation, and the overall composition and distribution of the sample available for the current research. Continued testing of results using a combination of methodologies, higher resolution CT scans, more robust sample sizes with approximately equal numbers of males and females, and samples composed of individuals from several different populations should help to further refine and evaluate the results of this study.

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APPENDIX I – CT Information by Case Number

Case #	Reference #	Pixel Size (mm)	Field of View (cm)	# Slices	Slice Thickness (mm)	Sex	Age
2	8281235	0.441	22.60	104	2	F	29
3	8281236	0.465	23.80	119	2	M	45
4	8291401	0.391	20.00	121	2	F	41
5	8291405	0.477	24.40	120	2	M	60
6	8291406	0.512	26.20	121	2	M	36
9	8291433	0.465	23.80	117	2	M	43
10	8281228	0.484	24.80	112	2	M	57
12	8281218	0.512	26.20	121	2	M	41
13	8281222	0.480	24.60	118	2	M	51
14	8291439	0.473	24.20	124	2	M	50
15	8291440	0.434	22.20	108	2	F	53
19	8291452	0.441	22.60	240	1	F	58
20	8291457	0.492	25.20	105	2	M	41
23	9051203	0.430	22.00	121	2	M	29
24	9090926	0.504	25.80	107	2	M	53
26	9090928	0.473	24.20	121	2	F	33
28	8291502	0.426	21.80	100	2	F	72
29	9011339	0.477	24.40	100	2	M	73
31	9021211	0.453	23.20	247	1	M	29
32	9021234	0.449	23.00	108	2	M	42
33	9021236	0.516	26.40	120	2	M	27
37	10221308	0.375	19.20	111	2	F	38
40	10221312	0.465	23.80	102	2	M	48
41	10221313	0.477	24.40	102	2	F	57
42	10231228	0.418	21.40	130	2	M	26
43	10231229	0.469	24.00	125	2	M	57
44	10231230	0.434	22.20	112	2	M	40
45	10231251	0.406	20.80	115	2	M	51
46	10221240	0.391	20.00	104	2	M	40
48	10221243	0.488	25.00	112	2	M	53
49	10221246	0.418	21.40	126	2	M	42
50	10221248	0.371	19.00	113	2	F	39
55	9101255	0.453	23.20	112	2	M	60
58	10221224	0.391	20.00	104	2	F	55
62	11181203	0.477	24.40	239	1	M	73
64	11181214	0.465	23.80	108	2	F	81
67	11181142	0.418	21.40	129	2	M	38
69	11181145	0.449	23.00	507	0.5	M	31
70	11181146	0.461	23.60	125	2	M	47
71	11031255	0.441	22.60	118	2	M	60
72	11031257	0.418	21.40	479	0.5	M	55
73a	11031258	0.430	22.00	123	2	M	84
73b	11031258	0.500	25.60	109	2	M	54
74	11181129	0.477	24.40	121	2	M	41
75	11181133	0.379	19.40	112	2	F	34
76	11031225	0.426	21.80	108	2	F	52
77	11031227	0.492	25.20	125	2	M	24
78	11031228	0.449	23.00	103	2	F	44
79	11031230	0.441	22.60	227	1	F	51
81	11031232	0.453	23.20	127	2	M	28
b	2271129	0.465	28.80	122	2	M	52
c	2271129	0.512	26.20	107	2	M	63
d	2271129	0.438	22.40	116	2	M	37
82	2271222	0.469	24.00	100	2	M	54
a	2271101	0.461	23.60	119	2	M	40
b	2271102	0.476	24.40	113	2	M	64
c	2271102	0.410	21.00	118	2	F	35

Case #	Reference #	Pixel Size (mm)	Field of View (cm)	# Slices	Slice Thickness (mm)	Sex	Age
b	2271145	0.472	24.20	126	2	M	53