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# Morphometric Assessment of the Internal Auditory Canal for Sex Determination in Subadults Using Cone Beam Computed Tomography (CBCT)

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# MORPHOMETRIC ASSESSMENT OF THE INTERNAL AUDITORY CANAL FOR SEX DETERMINATION IN SUBADULTS USING CONE BEAM COMPUTED TOMOGRAPHY (CBCT)

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Abstract

This study reports on the use of three methods for sex determination in subadults using the petrous portion of the temporal bone. The purpose of this study was to validate and refine two previously published methods of sex determination for the internal auditory canal as well as to develop a novel method. The sample was comprised of 276 cone beam computed tomography (CBCT) scans of a population of subadults age 6-24 (165 females, 111 males) divided into 5 age groups for analysis: Group 1 (age 6-10), Group 2 (age 11-13), Group 3 (age 14-16), Group 4 (age 17-19), and Group 5 (age 20-24). The first method evaluated was the lateral angle method, which failed to reliably predict sex in any age group. There were no statistically significant sex differences in lateral angle measurements for any age group. The second method evaluated and refined for this study was the diameter method. Statistically significant sex differences were found in age groups 2, 4, and 5 for some of the diameter variables. The new method developed for this study was the area method. Statistically significant sex differences were found in age groups 2, 3, and 4 for some of the area variables. A logistic function model including diameter and area variables was able to correctly allocate sex in groups 2, 3, and 4 with an overall accuracy ranging from 84.8% - 88.2%. The results of this study conclude that sexual dimorphism in the petrous portion of the temporal bone exists as early as 11 years old, and this difference can be reliably detected on CBCT scans.

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Dedication

To my family and friends,

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# Chapter 1 : Introduction

The identification of human remains is one of the most important aspects of forensic medicine. Scientific identification of human remains might involve odontology, genetics, dactyloscopy, and forensic radiology (Kahana & Hiss 1997). However, these techniques cannot be used in many situations. Factors such as normal chemical processes, the mechanism of death, or animal scavenging, may all have a deleterious effect on the state or preservation of the human remains. What usually survives both natural and unnatural processes is the skeleton (Kahana & Hiss 1997). Teeth and bones, which are composed of tissues more resistant against the effects of degradation than any others, often serve as a key tool in forensic identification (Bidmos 2010). Thus, even though a considerable amount of work within the discipline of modern forensic anthropology focuses on soft tissues, the study of the human skeleton – forensic osteology – is of utmost importance in the identification of human remains (Bidmos 2010). As a result, special attention in forensic anthropology has been given to the development and understanding of bone analysis and osteometric standards.

When skeletal remains are found, a biological profile must be reconstructed in order to understand the demographics of the population and the individual represented (Bidmos 2010). A biological profile typically includes age, sex, ancestry and stature, with sex being the most studied aspect of skeletal demography in anthropology (Bidmos 2010). Almost every bone of the human skeleton has been studied to this effect (Novotný, Işcan, & Loth 1993). Sex estimation is critical in initial identification of human remains as it immediately halves the possible choices (Acharya, Prabhu, &

Muddapur 2011). Furthermore, other biological variables, such as age at death, rely on the knowledge of sex of the individual (Bidmos 2010).

Much of the focus in the field of human osteology has emphasized the bones of the adult skeleton, yet the burials of subadults often represent up to half of the remains in many burial sites (Baker, Dupras, and Tocheri 2005). Many different terms are employed to describe individuals who are not yet considered mature adults, with no general consensus on exactly when an individual becomes an adult. Most textbooks mark the division at age 18 or 20 whereas others perceive adulthood as slightly earlier, at the end of puberty or adolescence (Baker et al. 2005). Individuals younger than adults can be referred to as subadults (Baker et al. 2005). In this study, individuals under the age of 25 are considered subadults.

Information in general human osteology texts and study collections of subadult materials are usually sparse, with many scientists avoiding working with subadult remains as it is perceived to be too difficult and time-consuming (Baker et al. 2005). The exclusion of subadults in bioarchaeological investigations often stems from the perception that the skeletal material is poorly preserved in comparison to that of adults, but also from unfamiliarity and a lack of recognition (Baker et al. 2005). Determining the sex of subadult skeletal remains at varying stages of development complicates their identification as the number of skeletal elements present and their appearance is quite variable. However, the sheer numbers of subadult skeletons in archaeological and forensic investigations make it increasingly necessary to counter their omission in osteological training and research.

Much of the focus in anthropological investigations of sex determination has been on the pelvis and skull, with correct sex determination reaching well over 95% (Graw, Wahl, & Albrecht 2004). However, in mass disaster situations, criminal cases, and war atrocities, these bones are often either fragmented or not well preserved, and they usually do not exhibit much sexual dimorphism until after puberty is reached. Thus, their value in determining sex in subadults is limited. The pars petrosa ossis temporalis is a dense, robust structure uniquely located in a protected location at the cranial base and is usually well preserved even in cremated remains (Wahl & Graw 2001; Noren, Lynnerup, Czarnetski, & Graw 2005; Graw et al. 2004). In addition, this region develops early, which lends potential for its use in sex determination in subadults (Gonçalves, Campanacho, & Cardoso 2011; Noren et al. 2005). The lateral angle method, which uses the petrous portion of the temporal bone for sex determination, was primarily developed by Wahl in 1981 and has shown some potential for sex determination (Noren et al. 2005). A few studies have been written since then to further explore its validity for sexing, but differences in methodology have led to conflicting results.

The purpose of this study was to use cone beam computed tomography (CBCT) to validate and refine two previously developed metric methods of sex determination using the internal auditory canal of the petrous temporal bone in a population of subadults. The techniques assessed included measurements of the lateral angle (Noren et al. 2005; Graw et al. 2004; Gonçalves et al. 2011; Akansel et al. 2008; Morgan, Lynnerup, & Hoppa 2013) and diameter of the internal auditory canal (Lynnerup, Schulz, Madelung, & Graw 2005). In addition, a new method measuring the cross-sectional area of the internal auditory canal was developed to assess if it would aid in sex determination for subadults.

## Research Questions and Hypotheses

1. Can morphometric measurements of the lateral angle, diameter, and cross-sectional area of the internal auditory canal, as measured on a CBCT scan, be used to accurately identify the sex of subadults?

    Hypothesis: Morphometric measurements of the lateral angle, diameter, and cross-sectional area of the internal auditory canal, as measured on a CBCT scan, can be used to accurately identify the sex of subadults.

    Null Hypothesis: Morphometric measurements of the lateral angle, diameter, and cross-sectional area of the internal auditory canal, as measured on a CBCT scan, cannot be used to accurately identify the sex of subadults.

2. How reliably can morphometric measurements of the lateral angle, diameter, and cross-sectional area of the internal auditory canal, as measured on a CBCT scan, identify the sex of subadults?

    Hypothesis: Morphometric measurements of the lateral angle, diameter, and cross-sectional area of the internal auditory canal, as measured on a CBCT scan, will identify the sex of subadults with an accuracy equal to or greater than 85%.

    Null Hypothesis: Morphometric measurements of the lateral angle, diameter, and cross-sectional area of the internal auditory canal, as measured on a CBCT scan, will identify the sex of subadults with an accuracy less than 85%.

Chapter 2 : Literature Review

## Sexual Dimorphism in the Human Skeleton

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). In humans, the difference is fundamentally chromosomal, with females having two X chromosomes and males having an X and a Y chromosome. The phenotypic differences between males and females are the result of hormones appearing in the correct order and at the appropriate time as a result of this chromosomal distinction. Sexual dimorphism thereby results from 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).

Sexual dimorphism in the skeleton becomes most apparent after puberty, during which a skeletal growth spurt occurs, gonads develop, secondary sex characteristics manifest, and body composition changes. Puberty marks the onset of adolescence and begins as early as age ten in females and twelve in males. Adolescence extends through the period of growth, generally culminating around age 14 in females and 16 in males, although these changes can vary in age and duration (Baker et al. 2005). As a consequence of differences in rate and duration of growth, sexual dimorphism manifests in the human skeleton in two primary forms: size and architecture. Males typically experience a longer and more intense growth spurt than females and thus develop larger, more robust skeletal elements (Byers 2005; Scheuer 2002). Females develop a pelvis architecturally adapted in size and shape to allow for childbirth (Byers 2005; Scheuer 2002). Determining the sex of the juvenile skeleton is a difficult task given that most of the features related to sexual differences in human bones are not present until after the onset of puberty.

## Methods of Sex Estimation

Traditionally, physical anthropologists have used two methods of skeletal sex estimation, namely morphological (non-metrical) and metrical. Morphological methods involve visual observation, rather than measurements, of bones that exhibit sexual dimorphism (as cited in Morgan 2009). Sexual dimorphism is most apparent in the pelvis, where reproductive differences are best seen (as cited in Morgan 2009). As such, scientists agree that it is the most reliable indicator for sex determination (as cited in Morgan 2009). The second most sexually dimorphic element is the cranium, where size and morphology are varied and best represented, followed by long bones and other postcranial, non-pelvic, elements (as cited in Morgan 2009). Although morphological methods can produce valuable results and are ideal for quick, preliminary assessments, they rely largely on the experience and level of expertise of the scientist and therefore involve a significant level of subjectivity. Therefore, morphologic methods are less desirable in forensic cases where objectivity and a high level of accuracy and confidence in results is extremely important (Rogers 2005).

The influence of subjectivity can be reduced through the utilization of multiple measurements (the metrical method) on bones that do not display obvious sexual differences. These measurements can be compared to standard measurements of specific skeletal elements and are considered to be more objective than morphological methods (Rogers 2005; Stewart 1979). Metrical methods involve subjecting a group of measurements to various forms of metrical analyses including the Student's *t-test*, indices, and discriminant function analysis. The metrical method is more structured than the morphological method and does not require extensive experience from the observer. Furthermore, it can be repeated to validate the obtained results.

Discriminant function analysis has proved to be the most reliable metrical approach and is therefore the most widely used (Bidmos 2010). This method explores how accurately participants can be classified into different groups on the basis of a set of measurements (Fan & Wang 1999). However, many discriminant function equations are population specific, and as such, equations derived for one population cannot be used on other, unrelated groups (Bidmos 2010). These equations are also affected by temporal change and therefore require revision over time (Bidmos 2010).

While discriminant function analysis has been widely used in the literature for sex determination, it is now often being replaced with logistic regression, a method which requires fewer theoretical assumptions and is easier to use and understand (Morgan 2009). According to Acharya et al. (2011), logistic regression analysis is considered to be better than discriminant function models since the former is more flexible in its assumptions – it can handle both discrete and continuous variables, which need not be normally distributed, linearly related, or of equal variance within each group. Given a binary (dichotomous) outcome, such as being male or female, and a battery of measurements on a set of continuous variables, such as morphometric measurements of the internal auditory canal, the probability of being classified as a male or female can be modeled by fitting the data to a logistic curve with the X axis representing the independent variable of choice and the Y axis representing the binary outcome (Fan & Wang 1999). The logistic regression score or *p*-value (always between 0 and 1) can then be used to classify sex in an unidentified individual while also providing a probability value for that allocation (Albanese, Eklics, & Tuck 2008). Scores over 0.5 represent males while scores under 0.5 represent females (Albanese et al. 2008). For example, a *p*-value of 0.89 would classify the unknown individual as a male, and the probability that this was correctly allocated would be 89%. Whereas discriminant function analysis strictly discriminates between males and females based on a calculation of precise numeral values, logistic regression is employed to assess the probability of being male or female, making it more appropriate for the prediction of sex in forensic contexts (as cited in Morgan 2009). According to Albanese (2003), a logistic regression model is only useful if the overall accuracy achieved is at least 85% with little bias in accuracy between males and females, with the measurements chosen minimally affected by population differences.

When attempting to determine sex, it is essential to examine as many skeletal features as possible and to use a combination of morphological and/or metric techniques in order to reduce the probability of error and achieve the most accurate estimation of sex possible (Morgan 2009). Over the last decade, scientists have continued to develop and modify both metric and morphological methods of sex determination in efforts to increase accuracy and address shortcomings of previous methodologies for sex determination in both archaeological and forensic research. Table 2.1, adapted from Novotný et al. 1993, represents the reliability of sex determination based on the percentage of correct and incorrect sex assignments.

Table 2.1.

*Reliability of Sex Determination Based on Percentage of Correct and Incorrect Sex Assignments*

| Reliability | Percent of Correct Sex Assignments (%) | Percent of Incorrect Sex Assignments (%) |
|---|---|---|
| Very Reliable | >60% | <10% |
| Reliable | >50% | <15% |
| Low Reliability | 50% | |
| Unreliable | <50% | >20% |

When most of the skeleton remains, sex is relatively uncomplicated to identify. Many researchers have claimed accuracies of 90-98% when sexing the pelvis bone alone, 80-90% from the skull alone, and 98% from the skull and pelvis together (Byers 2005; Günay and Altinkök 2000; Mays and Cox 2000; Krogman and İşcan; Scheuer 2002). However, only fragments of the skeleton often remain, making sex determination much more difficult. Therefore, it has become of increasing importance to develop sex determination methods that do not rely on the presence of several and/or intact bones. Skeletal remains that are usually well preserved provide for the highest diagnostic value. One particularl skeletal component with extreme mechanical strength is the *pars petrosa ossis temporalis*, or the petrous portion of the temporal bone, which is still preserved in corpses destroyed by fire (Graw, Wahl, & Ahlbrecht 2004).

### The Temporal Bone and the Pars Petrosa Temporalis

Petrous comes from the Latin word *petrosus*, meaning “stone-like, hard.” Due to its dense, robust structure and protected location at the cranial base, the petrous part of the temporal bone usually remains intact after cremation and thus can be used in anthropological investigations (Wahl & Graw 2001; Noren, Lynnerup, Czarnetski, &

Graw 2005). In addition, it is relatively unaffected by immediate environmental stimuli with regard to phenotypic change, and thus can provide access to the genotype (Sherwood 1995).

The development of the temporal bone is complex and unique, ossifying both interamembranously and endochondrally (Sherwood 1995). During early prenatal development and up to birth, the human temporal bone is made up of three components; the squama, the petrous portion, and the tympanic portion (Baker, Dupras, & Tocheri 2005). The petrous portion is formed endochondrally, and ossification begins between 20 and 24 weeks gestation, reaching 46% of its full size during the first 2 years of life (as cited in Sherwood 1995). Afterward, there is a marked decrease in development until complete cessation of growth at approximately 20 years of age (Noren et al. 2005).

The pars petrosa temporalis is a bilateral three-sided pyramid wedged in at the base of the skull between the sphenoid and occipital bones (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 temporal bone, and the anterior and posterior intracranial surfaces (Morgan 2009). The internal acoustic canal is a short canal found on the medial aspect of the posterior intracranial surface, or the facies posterior, and is oriented nearly perpendicular to the midsagittal plane (Morgan 2009). The internal acoustic canal begins with an oval opening on the facies posterior and extends laterally into the petrous bone, carrying the internal auditory artery and vein, facial nerve, intermediate nerve, and vestibulocochlear nerve (as cited in Morgan 2009). The petrous portion of the temporal bone assumes its characteristic shape early in fetal development and should not be confused with any other human element due to its blocky nature and large opening for the internal auditory meatus, making it a particularly useful structure to identify in fragmentary human remains (Baker, Dupras, & Tocheri 2005).

## The Lateral Angle Method

The angle at which the internal auditory canal opens up to the surface of the petrous bone, or the lateral angle, has been said to exhibit sexual dimorphism. Primarily developed by Wahl in 1981, the lateral angle method has also been discussed in other publications, but mainly in German. Little has been written internationally on this method, and as such, it was not well-known in the international physical anthropological community until more recently (Graw et al. 2003; Noren et al. 2005). Studies have reported that an angle above 45º is indicative of female sex while an angle below 45º is indicative of male sex (Ahlbrecht 1997; Graw et al. 2003). With previous studies showing a significant sexual dimorphism between juveniles (age 6+) and lateral angle size, the lateral angle may show potential for subadult sexing (as cited in Noren et al. 2005).

As it is impossible to measure the lateral angle directly off the surface of the petrous portion of the temporal bone, early studies measured the lateral angle indirectly by first taking impressions of the internal auditory canal. The cadaveric measurement method was originally developed by Wahl who was later criticized for his choice of clay as a casting material. An attempt to remedy this shortcoming was later made by substituting silicon casting material for clay (Noren et al. 2005). The use of the lateral angle of the internal acoustic canal has thus far proven inconclusive. Using direct measurements, Noren et al. (2005) was able to obtain an 83.2% accuracy in determining adult sex. However, using the same method, Graw et al. (2004) was only able to obtain

66% accuracy in their sample of adults. More recently, Gonçalves et al. (2011) attained only 62.9% accuracy in a sample of subadult skeletal remains.

Since methodological-related problems leading the casts to not fully reproduce the internal auditory canal may have contributed to the poor results obtained, computerized tomographic measurement of the lateral angle of the internal auditory canal has been evaluated as a substitute for direct anatomic measurement. Using computed tomography (CT) to measure the lateral angle in mostly adults, two studies have determined that while computerized tomography is capable of replicating the results of cadaveric measurements of the lateral angle, the lateral angle method provides low reliability for accurate sex determination and should only be used as supportive, rather than conclusive evidence (Akansel 2008; Morgan 2013). Nonetheless, tomographic studies are sparse and further studies are needed to either validate or refute these claims.

## Tomographic Imaging Techniques

Tomography is a general term used for an imaging technique that provides images by sectioning layers or planes of tissue, which can then be oriented to conform to a desired slice of the anatomy to be visualized. This technique is highly versatile and allows for accurate imaging of a wide variety of maxillofacial structures, including that of the internal auditory canal (Mah, Hatcher, & Harrell 2012). CT scanners, which were first developed in 1967, consist of an x-ray source and detector mounted on a rotating gantry with the patient at the center. As the gantry rotates around the patient, the detector detects the flux of x-rays that have passed through the patient (Sukovic 2003). A fan shaped x-ray beam from the x-ray source acquires a series of axial plane slices that are then stacked to create a three-dimensional reconstruction (Figure 2.1). As conventional medical CT devices are large and expensive, CBCT, or cone beam computed tomography, technology was later developed in the mid-1970s as a more cost-effective and efficient method for obtaining cross-sectional images for radiotherapy (Mah et al. 2012).

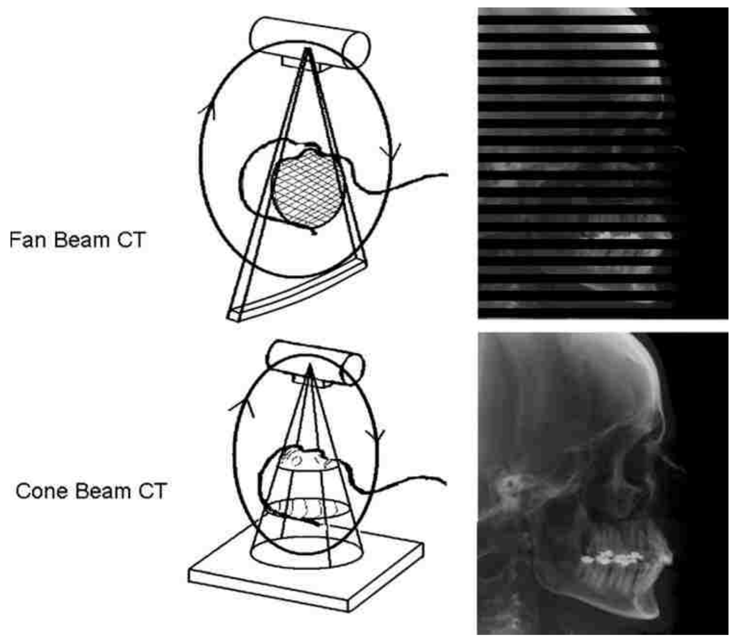



*Figure 2.1.* Comparison of fan beam and cone beam computed tomography imaging geometry. Adapted from "The Basics of Maxillofacial Cone Beam Computed Tomography," by A. G. Farman and W.C. Scarfe, 2009, Seminars in Orthodontics, 15 (1), p. 4. Copyright 2009 by Elsevier Inc.

CBCT scanners utilize a cone shaped beam (Figure 2.1) and a two-dimensional, or panel detector, which allows for a single rotation of the gantry to generate a scan of the entire head (Sukovic 2003). One advantage of CBCTs over conventional CTs is higher resolution and image accuracy. Because CBCT provides images of high contrasting structures well, it is well suited for evaluating hard tissue structures such as bone.

Volumetric data is comprised of a three-dimensional block of smaller cuboid structures, known as voxels, each representing a specific degree of x-ray absorption. The smaller the voxel size, the higher the resolution of the image. In conventional CT, the voxels are anisotropic rectangular cubes in which the voxel surfaces can be as small as 0.625 mm square, but with a depth that is usually in the order of 1-2 mm. Because of this anisotropy, image dimensions could be off as much as 1.5 mm as the scans take a series of slices that have small gaps in between them. The computer compensates for the small gaps and hides them by sophisticated algorithms, but the gaps still accumulate into a sizable margin of error (Farman & Scarfe, 2009). This difference in voxel size in each plane compromises precise measurements. Conversely, CBCT units provide isotropic voxels that are equal in all three dimensions, allowing precise measurements in all directions. CBCT voxel size often exceeds most high grade multi-slice CT capabilities in spatial resolution, with voxel dimensions from 0.4 mm to as little as 0.125 mm (Scarfe, Farman, Sukovic 2006). To date, there have been two published studies using the lateral angle method measured by CT to determine sex, but no studies have been done using CBCT. The higher resolution provided by CBCT may provide a significant advantage in capturing the most detail when examining a small, intricate structure such as the internal auditory canal. In addition, advances in software measurement tools may allow for more reliable and advanced diameter and cross-sectional area measurements in customized sections.

The first CT study to measure the lateral angle was conducted by Akansel et al. in 2008. The authors evaluated CT scans of 95 consecutive patients who underwent temporal bone CT for ear-related complaints. There were 49 females (age range: 5-75 years, mean: 36.1) and 46 males (age range: 6 months-67years, mean: 26.2). Axial images covering the temporal bone were obtained in 1 mm slices. The mean values for the lateral angle were 45.5 ± 7.1° for females and 41.0 ± 6.7° for males with a significance of $p < 0.01$. The lateral angle varied between 30° and 68° in females and 30° and 60° in males. Due to the significant overlap in ranges of measurements, no single cut-off value was able to satisfactorily differentiate between the genders. However, measurements of 35° and lesser were 93.6% specific for male gender and measurements of 60° and greater were 97.7% specific for female gender. When the subadults were concerned, the lateral angle did not show a significant difference between genders. However, there were only 22 subadults (5 females and 17 males). Furthermore, this study used CT scans of patients with ear-related complaints, and thus it can be argued that this was not a "normal" population. Future studies with larger sample sizes in both adult and subadult age groups from a "normal" population are needed. While sample sizes have been limited with medical CTs, the use of CBCT in orthodontics has provided a large database from a normal sample of both adults and subadults available for study.

Most recently, another computed tomographic study by Morgan et al. in 2013 was conducted to test the accuracy of the lateral angle method. The sample was composed of 77 postmortem CT scans of individuals of known age and sex (35 females, age 19-84, mean: 52; 42 males, age 24-84, mean: 46.4) taken in the Department of Forensic Medicine at the University of Copenhagen, Denmark. Using the 45° sectioning point recommended by Noren et al. (2005), they were only able to correctly allocate sex with an accuracy of 62.3%. This accuracy dropped even lower to 55.8% when logistic regression analysis was used. They concluded that the lateral angle method failed to consistently and reliably predict the sex of skeletal remains using the petrous portion of the temporal bone. At best, their results demonstrated that smaller lateral angles tended to be associated with males and larger lateral angles with females, suggesting the lateral angle method to be of little practical use for assessing sex in fragmentary remains. However, this study was not without its limitations. There were several imaging limitations related to the nature of the CT sample and postprocessing of the CT images, which may have introduced a significant source of error with regard to loss of spatial resolution. In addition, the CT scans were obtained at varying thicknesses (0.5-3 mm), with the majority of slice thicknesses 2 mm thick. This potentially introduces measurement error between scans that differed in slice thickness.

## The Diameter Method

Use of the lateral angle method for sex determination led to the development of other methods using the petrous portion of the temporal bone, including measurement of the diameter of the medial opening of the internal auditory canal. In 2006, Lynnerup examined the diameter of the internal auditory meatus using 113 left petrous bones of known sex and age (48 females, age range 23-88; 65 males, age range 19-93). This study reported disappointing results for the predictive power of the diameter in terms of correct sexing. However, the authors measured the diameter using a suite of ordinary drill bits, ranging from one to ten mm in half mm increments, which were inserted into the canal. The diameter thus recorded was the diameter of the largest drill that would fit inside the internal meatus. As the internal porus is seldom circular, but rather oblique, simply determining the diameter as if the opening were circular represents a major reduction.

Nonetheless, based on the distribution of diameter size between males and females, the authors published the following sectioning points: a diameter of less than 3.0 mm is indicative of females and a diameter greater than, or equal to 3.5 mm is indicative of males. These sectioning points produced a 70% predictive value for correct sexing, but subadults were not included in the study.

In 2009, Morgan attempted to validate Lynnerup's study by measuring the diameter of the internal auditory canal on the same CT slices in which the lateral angles were measured. Diameters were measured at the opening of the internal auditory meatus as well as at distances of 1 mm and 2 mm from the opening. This 2 mm stop point was decided upon based on the observation that the majority of canals curved beyond 2 mm, which would have impeded the insertion of an object such as a drill bit from entering further. The author found that the diameter method could not accurately predict the sex using the sectioning points provided by Lynnerup et al. (2006). The results also did not reveal any statistically significant differences between male female means for any of the three diameter measurements. CT scanner isotropy lends the best image resolution in the axial plane, so the diameter measurements were all taken on the axial plane. Due to the reduced resolution of the CT scans in the sagittal and coronal planes, Morgan was unable to generate a 3-D image of the canal for taking a vertical diameter. Also, because the majority of the data was obtained at a slice thickness of 2 mm and the internal acoustic canal is a particularly small structure, the canal was visible in only 2-3 slices for each individual. This resulted in a flattened negative cast, rather than the characteristic cone shape, of the canal. Thinner CT slices would have improved the resolution issue for the orthogonal planes.

# Chapter 3 : Methodology

The following protocol, #1405-4805M, was reviewed by the Office of Research Integrity – Human Subjects at the University of Nevada, Las Vegas, and deemed excluded from IRB review (Appendix A).

## Sampling Procedure

A sample of 360 first come, first serve, anonymized CBCT scans from the patient database at the University of Nevada, Las Vegas Department of Orthodontics and Dentofacial Orthopedics, taken in the period from August 2006 to December 2013, was used. All CBCT scans were taken by one radiology technician, who had adequate training in the technique and operation of the CBCT machine (CB MercuRay, Hitachi Medical Corp). Scans were taken under the following parameters: matrix: 512 x 512, FOV: 193 mm, kV: 100, mA: 15, exposure time; 10 seconds. The data was sent directly to a UNLV School of Dental Medicine computer with password protected access and stored in Digital Imaging and Communications in Medicine format (DICOM). Volumetric renderings of subjects' CBCT scans were evaluated with InvivoDental version 5.3 software (Anatomage, San Jose, CA).

CBCT scans were selected based on the quality of the scan and the ease of identification of the internal acoustic canal and its surrounding anatomical structures. Exclusion criteria included previous medical history with any developmental syndrome or disorder that could affect craniofacial development and any data sets which did not clearly illustrate the canal opening as well as the canal apex. 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.

After the exclusion of low quality CBCT scans and scans in which the canal apex with not within the field of view, 300 CBCTs remained. The sample was comprised of 182 females and 118 males under the age of 25, divided into the following age groups:

Group 1: Age 6-10

Group 2: Age 11-13

Group 3: Age 14-16

Group 4: Age 17-19

Group 5: Age 20-24

**Adjustment for Head Position, Brightness, and Contrast**

All CBCT scans were oriented in a standardized head position. This was done by first examining the axial section at the level of the odontoid process of the atlas bone (C2) and orienting the head such that a vertical line would approximate the midline of both the odontoid process and the maxilla. Next, the sagittal section was oriented such that the hard palate would be parallel to the bottom of the computer monitor. In the coronal section in which both mandibular condyles were approximately equal in size and shape, the image was rotated such that a vertical line would approximate the midline of the oropharyngeal airway (Figure 3.1).

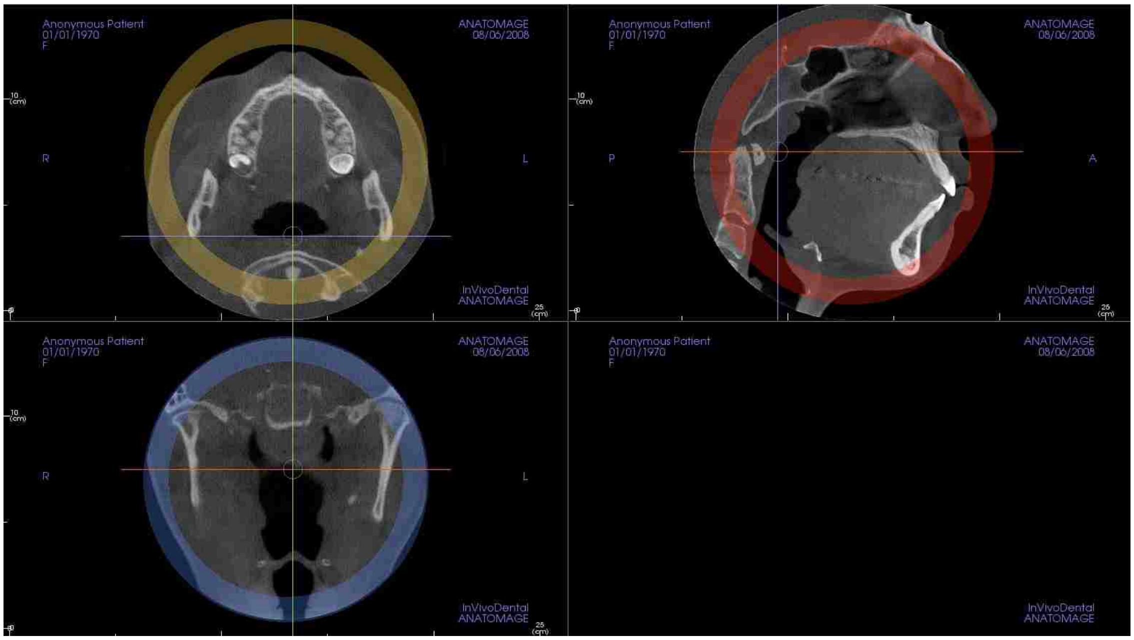



*Figure 3.1.* Orientation in standardized head position, showing adjustments made in axial, coronal, and sagittal planes.

After adjustment in each of the three planar views, adjustments were made for brightness and contrast. The brightness was adjusted by selecting the sagittal slice in which the maxillary sinus was most visible. Brightness was adjusted such that the blackness in the maxillary sinus was the same as the blackness in the periphery or background of the image (Figure 3.2). Contrast was adjusted such that the trabeculations in the mandible showed the most detail (Figure 3.3).

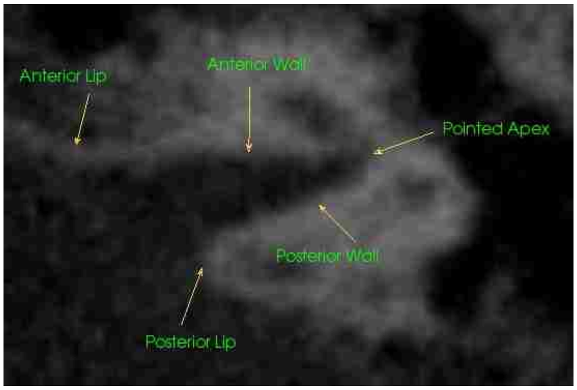
*Figure 3.2.* Adjustment for Brightness. Sagittal slice with maxillary sinus shown. Blackness in sinus matches blackness in the periphery or background.

*Figure 3.3.* Adjustment for contrast. Trabeculae detail clearly visible.

## Measurement of the Lateral Angle

Within the InVivo 5.3 software, the "Arch Section" tab was used to view an axial section of the petrous temporal bone. Slice thicknesses were set at 2.0 mm, and slice increments of 0.1 mm were used to choose the best slice from which to measure the lateral angle. Although it has been shown that there is a lack of significant difference between left and right temporal bone measurements (Noren et al. 2005), both the left and right lateral angles were measured whenever possible.

To replicate the methods in prior CT studies, the axial CBCT slice (examined in 0.1 mm intervals) in which the apex of the internal auditory canal was most pointed (Figure 3.4 (left) and Figure 3.5 (right). *Internal auditory canal. Incudomalleal joint and pointed apex clearly visible.*) was used (Akansel et. al 2008). For most cases, this was the next higher slice to the one that showed the incudomalleal joint (ice cream in cone) most clearly (Figure 3.4 (left) and Figure 3.5 (right). *Internal auditory canal. Incudomalleal joint and pointed apex clearly visible.*). A line (ignoring local surface irregularities) was drawn to connect the anterior and posterior lips of the meatus. A second line (ignoring local surface irregularities) was drawn to connect the anterior lip of the meatus to the most anterior point of the anterior wall of the internal auditory canal. The smaller of the angles that form at the point of their intersection was recorded as the anterior lateral angle (Figure 3.6). To replicate the methods in several prior casting studies (Masotti, Succi-Leonelli, & Gualdi-Russo 2013; Todd, Graw, & Dietzel 2010; Gonçalves et al. 2011), an additional angle using the posterior wall of the auditory canal instead of the anterior wall was recorded as the posterior lateral angle (Figure 3.6).



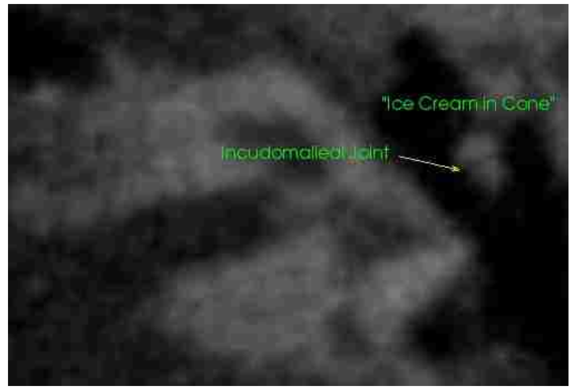



*Figure 3.4 (left) and Figure 3.5 (right).* Internal auditory canal. Incudomalleal joint and pointed apex clearly visible.

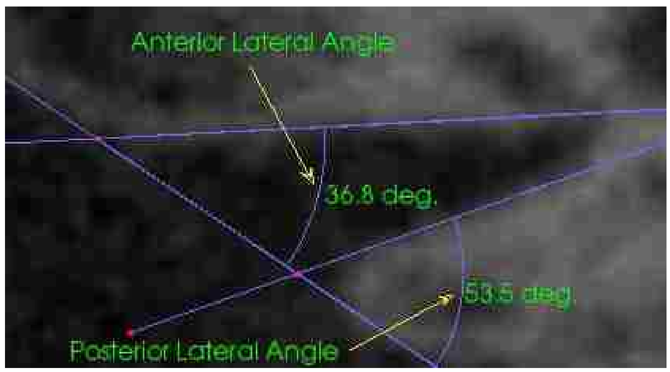



*Figure 3.6.* Measurement of the anterior and posterior lateral angle.

### Measurement of the Cross-Sectional Area

Under the same "Arch Section" tab in Invivo, a perpendicular spline was drawn to begin at the same line previously drawn connecting the anterior and posterior lips of the meatus. Using a slice thickness of 2.0 mm and a slice interval of 2 mm, custom sections were made to view the canal in cross sections at 0, 2, 4, 6, and 8 mm from the opening of the internal auditory meatus. As the opening of the canal is funnel shaped with no clearly delineated border, the first cross-sectional area measurement started at the section 2 mm lateral to the opening of the canal. Subsequent measurements were also recorded in the slices 4, 6, and 8 mm lateral to the meatus when a canal border could be clearly delineated. If no border was clearly visible, the canal was not outlined and the area was not recorded (Figure 3.7). A minimum of 12-15 points were used to trace the periphery of the canal on each slice.

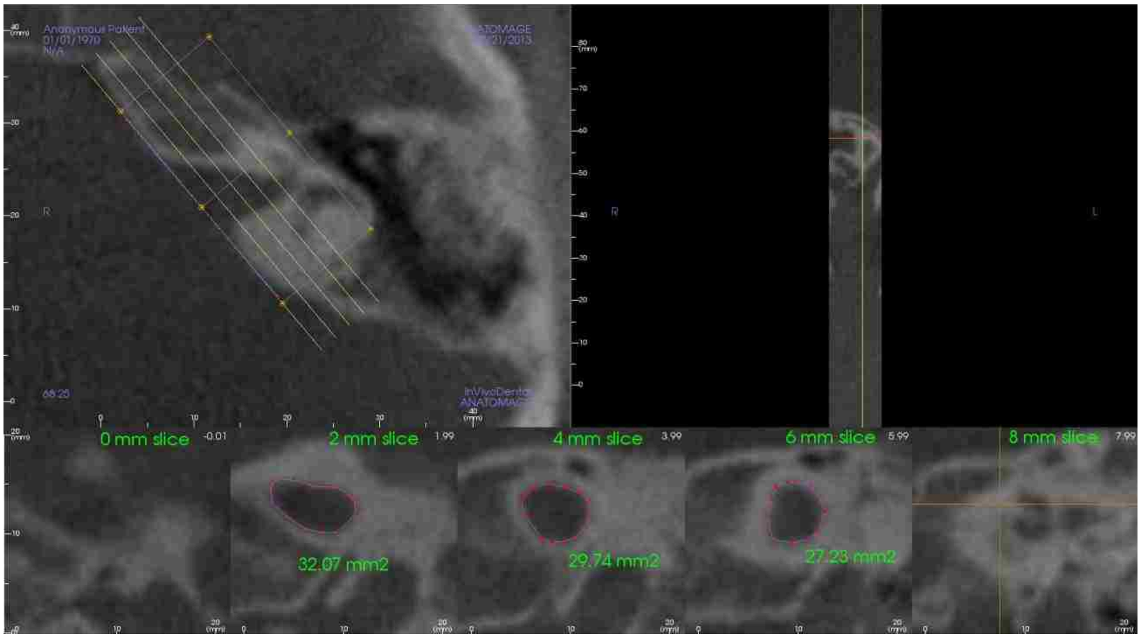



*Figure 3.7.* Arch spline drawn to create custom sections starting at 0 mm, 2 mm, 4 mm, 6 mm, and 8 mm lateral to the internal auditory meatus. Canal periphery traced on sections with clearly delineated borders.

**Measurement of the Diameter**

Using the same custom sections of the internal auditory canal in which the cross-sectional areas were measured, the largest diameter approximating the center of the canal was measured. The diameter was recorded at 2 mm, 4 mm, 6 mm, and 8 mm from the internal auditory meatus except for in the sections in which the borders of the canal could not be delineated and traced (Figure 3.8).

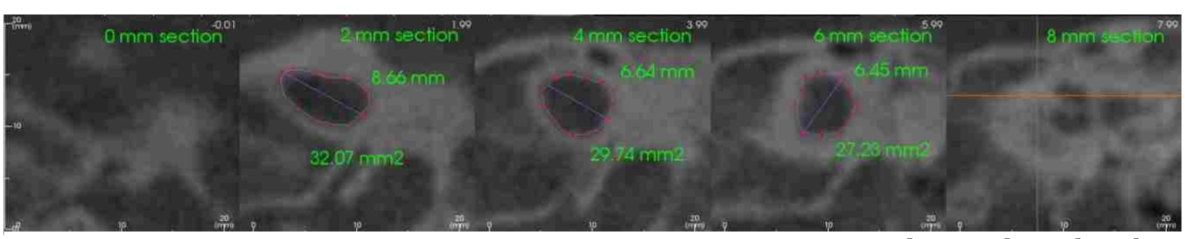



*Figure 3.8.* Custom sections starting at 0 mm, 2 mm, 4 mm, 6 mm, and 8 mm lateral to the internal auditory meatus. Measurement of the largest diameter approximating the center of each traced canal shown.

## Statistics

First, in order to test the reproducibility of the collected measurements, 10 cases were randomly selected for intra-observer error testing. The CBCT data was opened in its anonymized .INV format, without knowledge of the true age and sex of the individuals, and all of the procedures as outlined above were repeated. The intra-observer test was performed with a two month interval between the original and re-tested measurements. To compare differences between contralateral linear and angular measurements within the same individual, a paired t-test was used.

The results of each method were then compared against known sex. All linear and angular variables measurements were transferred and organized according to age group and gender. Statistical analysis was conducted using the Statistical Package for the Social Sciences (SPSS) version 22.0.

The anterior and posterior lateral angles were individually assessed to predict the sex by following the sectioning point reported by Noren 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 (Noren et al., 2005).

The diameters and cross-sectional areas at 2 mm, 4 mm, 6 mm, and 8 mm (when present) were each assessed independently for sexual differences within each age group. 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 and cross-sectional areas.

Differences between mean angular, linear, and area measurements in each age group were examined using an independent-samples *t*-test. Frequency tables were created to analyze distribution of linear measurements in each age group. All diameter and area measurements were included in a logistic regression analysis to determine if a model could be formed to predict both the sex and the probability of correct sex allocation.

Chapter 4 : Results

## Bilateral Sample

Independent samples t tests indicated no significant differences in the mean anterior and posterior lateral angle size (Table 4.1), diameters (Table 4.2), or cross-sectional areas (Table 4.3) between the left and right temporal bones. Therefore, in order to remain consistent with previous research methods, which also documented a lack of significance between sides in this cranial element (Morgan, 2009; Akansel et al., 2008; Lynnerup et al., 2006; Noren et al., 2005), only the left side was used to analyze the sex differences for each method.

Bilateral measurements were not possible on all samples due to poor visibility of the apex or periphery of the internal auditory canal. From the original sample size of 300, measurements for the anterior and posterior lateral angle were taken from both the left and right sides in 252 cases. For the remaining 47 cases, 24 met the protocol outlined for selecting the appropriate CBCT slice for the left side only and 23 met the protocol for the right side only. Since only the left temporal bone was used for the statistical analyses, the resultant sample size for the anterior and posterior lateral angle statistical analyses was 276. Similarly, since the diameters and cross-sectional areas were not measurable for every case at each section, the sample sizes used in statistical analyses for the left diameters and cross-sectional areas at 2 mm, 4 mm, 6 mm, and 8 mm were 231, 274, 249, and 146, respectively.

Table 4.1

*Comparing the Left and Right Means of the Lateral Angle*

| | Side | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Anterior Lateral Angle | Right | 275 | 46.551 | 10.3108 | .6218 |
| | Left | 276 | 46.117 | 10.3218 | .6202 |
| Posterior Lateral Angle | Right | 275 | 50.6644 | 10.45881 | .63069 |
| | Left | 276 | 52.2111 | 10.79443 | .64857 |

*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 Difference | Std. Error Difference | Lower | Upper |
| Anterior Lateral Angle | Equal variances assumed | .091 | .763 | .494 | 550 | .622 | .4336 | .8782 | -1.291 | 2.1586 |
| | Equal variances not assumed | | | .494 | 549.979 | .622 | .4336 | .8782 | -1.291 | 2.1586 |
| Posterior Lateral Angle | Equal variances assumed | .079 | .779 | -1.710 | 550 | .088 | -1.54672 | .90477 | -3.324 | .23051 |
| | Equal variances not assumed | | | -1.710 | 549.675 | .088 | -1.54672 | .90466 | -3.324 | .23030 |

Table 4.2

*Comparing the Left and Right Means of the Canal Diameters*

| | Side | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Diameter 2 | Right | 221 | 8.82 | 1.783 | .120 |
| | Left | 231 | 9.16 | 1.851 | .122 |
| Diameter 4 | Right | 272 | 7.6124 | 1.57084 | .09525 |
| | Left | 274 | 7.6400 | 1.59627 | .09643 |
| Diameter 6 | Right | 238 | 6.7248 | 1.35887 | .08808 |
| | Left | 249 | 6.7943 | 1.28764 | .08160 |
| Diameter 8 | Right | 136 | 6.2243 | 1.09031 | .09349 |
| | Left | 146 | 6.4905 | 2.10213 | .17397 |

*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 Difference | Std. Error Difference | Lower | Upper |
| Diam 2 | Equal variances assumed | .080 | .777 | -1.949 | 450 | .052 | -.333 | .171 | -.670 | .003 |
| | Equal variances not assumed | | | -1.951 | 449.976 | .052 | -.333 | .171 | -.669 | .002 |
| Diam 4 | Equal variances assumed | .070 | .791 | -.204 | 544 | .839 | -.02761 | .13555 | -.2939 | .23865 |
| | Equal variances not assumed | | | -.204 | 543.959 | .839 | -.02761 | .13554 | -.2939 | .23864 |
| Diam 6 | Equal variances assumed | .059 | .808 | -.579 | 485 | .563 | -.06947 | .11993 | -.3051 | .16617 |
| | Equal variances not assumed | | | -.579 | 480.293 | .563 | -.06947 | .12007 | -.3054 | .16647 |
| Diam 8 | Equal variances assumed | 1.492 | .223 | -1.321 | 280 | .188 | -.26628 | .20159 | -.6631 | .13055 |
| | Equal variances not assumed | | | -1.348 | 221.043 | .179 | -.26628 | .19750 | -.6555 | .12295 |

Table 4.3

*Comparing the Left and Right Means of the Canal Cross-Sectional Areas*

| | Side | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Area 2 | Right | 224 | 31.4356 | 9.77849 | .65335 |
| | Left | 231 | 32.4385 | 11.08257 | .72918 |
| Area 4 | Right | 272 | 29.5729 | 9.29732 | .56373 |
| | Left | 273 | 29.2586 | 10.43091 | .63131 |
| Area 6 | Right | 238 | 27.6464 | 8.53029 | .55294 |
| | Left | 250 | 28.1851 | 8.91942 | .56411 |
| Area 8 | Right | 133 | 24.8853 | 7.17693 | .62232 |
| | Left | 146 | 26.1733 | 7.71769 | .63872 |

*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 Difference | Std. Error Difference | Lower | Upper |
| Area 2 | Equal variances assumed | 1.443 | .230 | -1.022 | 453 | .307 | -1.00290 | .98095 | -2.9307 | .92487 |
| | Equal variances not assumed | | | -1.024 | 449.039 | .306 | -1.00290 | .97907 | -2.9270 | .92122 |
| Area 4 | Equal variances assumed | .290 | .590 | .371 | 543 | .711 | .31433 | .84655 | -1.3486 | 1.97724 |
| | Equal variances not assumed | | | .371 | 536.404 | .710 | .31433 | .84637 | -1.3483 | 1.97694 |
| Area 6 | Equal variances assumed | .628 | .429 | -.681 | 486 | .496 | -.53873 | .79078 | -2.0925 | 1.01504 |
| | Equal variances not assumed | | | -.682 | 485.989 | .496 | -.53873 | .78991 | -2.0908 | 1.01333 |
| Area 8 | Equal variances assumed | 1.934 | .165 | -1.439 | 277 | .151 | -1.28802 | .89479 | -3.0495 | .47344 |
| | Equal variances not assumed | | | -1.444 | 276.879 | .150 | -1.28802 | .89177 | -3.0435 | .46748 |

**Age Distribution**

The age distribution of the 276 individuals evaluated in this study ranged from 6-24 years with a mean age of 13.67 years. For the 165 females, age ranged from 7-24, with a mean age of 13.56. For the 111 males, ages ranged from 6-24, with a mean age of 13.94. Despite the considerably smaller sample of males, the age distribution between the sexes was similar, and an independent samples t test revealed that there were no statistically significant differences between the male and female mean values for age ($p$ = 0.208). Table 4.4 shows the breakdown of the sample size and mean age for each age group.

Table 4.4

*Sample Distribution of each Age Group According to Gender and Chronological Age*

| *Group* | *Age* | *Gender* | *Mean Age with Standard Deviation* | *Sample Size* | *Total Sample Size* |
|---|---|---|---|---|---|
| 1 | 6-10 | *Female* | 9.67 +/- 0.93 | 39 | 51 |
| | | *Male* | 9.20 +/- 1.29 | 12 | |
| 2 | 11-13 | *Female* | 12.46 +/- 0.82 | 59 | 109 |
| | | *Male* | 12.57 +/- 0.91 | 50 | |
| 3 | 14-16 | *Female* | 15.14 +/- 0.76 | 42 | 79 |
| | | *Male* | 15.39 +/- 0.80 | 37 | |
| 4 | 17-19 | *Female* | 18.23 +/- 0.71 | 15 | 22 |
| | | *Male* | 18.14 +/- 0.76 | 7 | |
| 5 | 20-24 | *Female* | 21.59 +/- 1.43 | 10 | 15 |
| | | *Male* | 22.47 +/- 1.48 | 5 | |

## 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 females, 4 males) 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 4.5). No statistically significant difference was found between the first and second measurements for the anterior ($p$ = .193) and posterior ($p$ = .302) lateral angles, diameter of the openings at 2 mm ($p$ = .061), 4 mm ($p$ = .256), 6 mm ($p$ = .491), and 8 mm ($p$ = .586), or cross-sectional area at 2 mm ($p$ = .216), 4 mm ($p$ = .488), 6 mm ($p$ = .476), and 8 mm ($p$ = 0.860). Overall, there was good intra-observer agreement for each of the previously outlined methods.

Table 4.5

*Analysis of Intra-Observer Error*

| | | Paired Differences | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 95% Confidence Interval of the Difference | | | | |
| | | Mean | Std. Deviation | Std. Error Mean | Lower | Upper | t | df | Sig. (2-tailed) |
| Pair 1 | Ant LA-1 - Ant LA-2 | -4.7700 | 10.71635 | 3.38881 | -12.43601 | 2.89601 | -1.408 | 9 | .193 |
| Pair 2 | Post LA-1 - Post LA-2 | -2.7400 | 7.90685 | 2.50036 | -8.39622 | 2.91622 | -1.096 | 9 | .302 |
| Pair 3 | Diam 2-1 - Diam 2-2 | 1.0450 | 1.54198 | .48762 | -.05807 | 2.14807 | 2.143 | 9 | .061 |
| Pair 4 | Diam 4-1 - Diam 4-2 | .23500 | .61205 | .19355 | -.20283 | .67283 | 1.214 | 9 | .256 |
| Pair 5 | Diam 6-1 - Diam 6-2 | -.19800 | .87252 | .27591 | -.82216 | .42616 | -.718 | 9 | .491 |
| Pair 6 | Diam 8-1 Diam 8-2 | -.36500 | 2.04612 | .64704 | -1.82871 | 1.09871 | -.564 | 9 | .586 |
| Pair 7 | Area 2-1 - Area 2-2 | 3.97800 | 9.46231 | 2.99225 | -2.79093 | 10.74693 | 1.329 | 9 | .216 |
| Pair 8 | Area 4-1 - Area 4-2 | -2.2040 | 9.63533 | 3.04696 | -9.09670 | 4.68870 | -.723 | 9 | .488 |
| Pair 9 | Area 6-1 - Area 6-2 | 1.4350 | 6.10724 | 1.93128 | -2.93386 | 5.80386 | .743 | 9 | .476 |
| Pair 10 | Area 8-1 - Area 8-2 | .52200 | 9.06951 | 2.86803 | -5.96594 | 7.00994 | .182 | 9 | .860 |

## Lateral Angle Method

Descriptive statistics which summarize the results for the left anterior and posterior lateral angle measurements for each age group can be found in Table 4.6, Table 4.9, Table 4.12, Table 4.15, and Table 4.18. Sex was predicted within each age group using Noren 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.

For males in age group 1 (age 6-10), an accurate prediction of sex in the CBCT sample occurred 9 (75%) times out of 12, while for females accurate prediction only occurred 18 (46.2%) times out of 39 (Table 4.7). In total, 27 out of 51 cases were correctly sexed, with an overall accuracy of 52.9%. When using the posterior lateral angle, accurate sex prediction occurred 29 times (74.4%) out of 39 in females and 6 (50.0%) times out of 12 in males (Table 4.8). In total, 35 out of 51 cases were correctly sexed, with a slightly higher overall accuracy of 68.6%.

Table 4.6

*Descriptive Statistics for the Left Lateral Angle in Group 1 (age 6-10)*

| | Side | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Ant LA | Left | 51 | 45.4235 | 9.71828 | 1.37437 |
| Post LA | Left | 51 | 51.1961 | 9.98430 | 1.41199 |

Table 4.7

*Sex Predictive Value of Noren et al.'s (2005) Lateral Angle Sectioning Point Using Anterior Lateral Angle Measurements in Age Group 1 (Age 6-10)*

| | | | Predicted Sex | | |
|---|---|---|---|---|---|
| | | | Female | Male | Total |
| True Sex | F | Count | 18 | 21 | 39 |
| | | Expected Count | 16.1 | 22.9 | 39.0 |
| | | % within true sex | 46.2% | 53.8% | 100.0% |
| | | % within predicted sex | 85.7% | 53.8% | 76.5% |
| | | % of total | 35.3% | 41.2% | 76.5% |
| | M | Count | 3.0 | 9.0 | 12.0 |
| | | Expected Count | 4.9 | 7.1 | 12.0 |
| | | % within true sex | 25.0% | 75.0% | 100.0% |
| | | % within predicted sex | 14.3% | 30.0% | 23.5% |
| | | % of total | 5.9% | 17.6% | 23.5% |
| Total | | Count | 21.0 | 30.0 | 51.0 |
| | | Expected Count | 21 | 30 | 51 |
| | | % within true sex | 41.2% | 58.8% | 100.0% |
| | | % within predicted sex | 100.0% | 100.0% | 200.0% |
| | | % of total | 41.2% | 58.8% | 100.0% |

Table 4.8

*Sex Predictive Value of Noren et al.'s (2005) Lateral Angle Sectioning Point Using Posterior Lateral Angle Measurements in Age Group 1 (Age 6-10)*

| | | | Predicted Sex | | |
|---|---|---|---|---|---|
| | | | Female | Male | Total |
| True Sex | F | Count | 29 | 10 | 39 |
| | | Expected Count | 26.8 | 12.2 | 39.0 |
| | | % within true sex | 74.4% | 25.6% | 100.0% |
| | | % within predicted sex | 82.9% | 25.6% | 76.5% |
| | | % of total | 56.9% | 19.6% | 76.5% |
| | M | Count | 6.0 | 6.0 | 12.0 |
| | | Expected Count | 8.2 | 3.8 | 12.0 |
| | | % within true sex | 50.0% | 50.0% | 100.0% |
| | | % within predicted sex | 17.1% | 37.5% | 23.5% |
| | | % of total | 11.8% | 11.8% | 23.5% |
| Total | | Count | 35.0 | 16.0 | 51.0 |
| | | Expected Count | 35 | 16 | 51 |
| | | % within true sex | 68.6% | 31.4% | 100.0% |
| | | % within predicted sex | 100.0% | 100.0% | 200.0% |
| | | % of total | 68.6% | 31.4% | 100.0% |

For males in age group 2 (11-13), an accurate prediction of sex in the CBCT sample occurred 30 (60.0%) times out of 50, while for females accurate prediction occurred 29 (49.2%) times out of 59 when using the anterior lateral angle (Table 4.10).

In total, 59 out of 109 cases were correctly sexed, with an overall accuracy of 54.1%. When using the posterior lateral angle, accurate sex prediction occurred 47 times (79.7%) out of 59 in females and 14 (28.0%) times out of 50 in males (Table 4.11). In total, 61 out of 109 cases were correctly sexed, with a slightly higher overall accuracy of 55.9%.

Table 4.9

*Descriptive Statistics for the Left Lateral Angle in Group 2 (age 11-13)*

| | Side | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Ant LA | Left | 109 | 45.66055 | 10.72368 | 1.031886 |
| Post LA | Left | 109 | 51.94358 | 11.02445 | 1.060828 |

Table 4.10

*Sex Predictive Value of Noren et al.'s (2005) Lateral Angle Sectioning Point Using Anterior Lateral Angle Measurements in Age Group 2 (Age 11-13)*

| | | | Predicted Sex | | |
|---|---|---|---|---|---|
| | | | Female | Male | Total |
| True Sex | F | Count | 29 | 30 | 59 |
| | | Expected Count | 26.5 | 32.5 | 59.0 |
| | | % within true sex | 49.2% | 50.8% | 100.0% |
| | | % within predicted sex | 59.2% | 50.8% | 54.1% |
| | | % of total | 26.6% | 27.5% | 54.1% |
| | M | Count | 20 | 30 | 50 |
| | | Expected Count | 22.5 | 27.5 | 50.0 |
| | | % within true sex | 40.0% | 60.0% | 100.0% |
| | | % within predicted sex | 40.8% | 50.0% | 45.9% |
| | | % of total | 18.3% | 27.5% | 45.9% |
| Total | | Count | 49 | 60 | 109 |
| | | Expected Count | 49.0 | 60.0 | 109.0 |
| | | % within true sex | 45.0% | 55.0% | 100.0% |
| | | % within predicted sex | 100.0% | 100.0% | 200.0% |
| | | % of total | 45.0% | 55.0% | 100.0% |

Table 4.11

*Sex Predictive Value of Noren et al.'s (2005) Lateral Angle Sectioning Point Using Posterior Lateral Angle Measurements in Age Group 2 (Age 11-13)*

| | | | Predicted Sex | | |
|---|---|---|---|---|---|
| | | | Female | Male | Total |
| True Sex | F | Count | 47 | 12 | 59 |
| | | Expected Count | 44.9 | 14.1 | 59.0 |
| | | % within true sex | 79.7% | 20.3% | 100.0% |
| | | % within predicted sex | 56.6% | 20.3% | 54.1% |
| | | % of total | 43.1% | 11.0% | 54.1% |
| | M | Count | 36 | 14 | 50 |
| | | Expected Count | 38.1 | 11.9 | 50.0 |
| | | % within true sex | 72.0% | 28.0% | 100.0% |
| | | % within predicted sex | 43.4% | 53.8% | 45.9% |
| | | % of total | 33.0% | 12.8% | 45.9% |
| Total | | Count | 83 | 26 | 109 |
| | | Expected Count | 83.0 | 26.0 | 109.0 |
| | | % within true sex | 76.1% | 23.9% | 100.0% |
| | | % within predicted sex | 100.0% | 100.0% | 200.0% |
| | | % of total | 76.1% | 23.9% | 100.0% |

For males in age group 3 (14-16), an accurate prediction of sex in the CBCT sample occurred 22 (59.5%) times out of 37, while for females accurate prediction occurred 27 (64.3%) times out of 42 (Table 4.13). In total, 49 out of 79 cases were correctly sexed, with an overall accuracy of 62.0%. When using the posterior lateral angle, accurate sex prediction occurred 35 times (83.3%) out of 42 in females and 12 (32.4%) times out of 37 in males (Table 4.14). In total, 47 out of 79 cases were correctly sexed, with a slightly lower overall accuracy of 59.5%.

Table 4.12

*Descriptive Statistics for the Left Lateral Angle in Group 3 (age 14-16)*

| | Side | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Ant LA | Left | 79 | 47.54177 | 10.53091 | 1.192391 |
| Post LA | Left | 79 | 52.98127 | 11.11963 | 1.25905 |

Table 4.13

*Sex Predictive Value of Noren et al.'s (2005) Lateral Angle Sectioning Point Using Anterior Lateral Angle Measurements in Age Group 3 (Age 14-16)*

| | | | Predicted Sex | | |
|---|---|---|---|---|---|
| | | | Female | Male | Total |
| True Sex | F | Count | 27 | 15 | 42 |
| | | Expected Count | 22.3 | 19.7 | 42.0 |
| | | % within true sex | 64.3% | 35.7% | 100.0% |
| | | % within predicted sex | 64.3% | 35.7% | 53.2% |
| | | % of total | 34.2% | 19.0% | 53.2% |
| | M | Count | 15 | 22 | 37 |
| | | Expected Count | 19.7 | 17.3 | 37.0 |
| | | % within true sex | 40.5% | 59.5% | 100.0% |
| | | % within predicted sex | 35.7% | 59.5% | 46.8% |
| | | % of total | 19.0% | 27.8% | 46.8% |
| Total | | Count | 42 | 37 | 79 |
| | | Expected Count | 42.0 | 37.0 | 79.0 |
| | | % within true sex | 53.2% | 46.8% | 100.0% |
| | | % within predicted sex | 100.0% | 100.0% | 200.0% |
| | | % of total | 53.2% | 46.8% | 100.0% |

Table 4.14

*Sex Predictive Value of Noren et al.'s (2005) Lateral Angle Sectioning Point Using Posterior Lateral Angle Measurements in Age Group 3 (Age 14-16)*

| | | | Predicted Sex | | |
|---|---|---|---|---|---|
| | | | Female | Male | Total |
| True Sex | F | Count | 35 | 7 | 42 |
| | | Expected Count | 31.9 | 10.1 | 42.0 |
| | | % within true sex | 83.3% | 16.7% | 100.0% |
| | | % within predicted sex | 58.3% | 16.7% | 53.2% |
| | | % of total | 44.3% | 8.9% | 53.2% |
| | M | Count | 25 | 12 | 37 |
| | | Expected Count | 28.1 | 8.9 | 37.0 |
| | | % within true sex | 67.6% | 32.4% | 100.0% |
| | | % within predicted sex | 41.7% | 63.2% | 46.8% |
| | | % of total | 31.6% | 15.2% | 46.8% |
| Total | | Count | 60 | 19 | 79 |
| | | Expected Count | 60.0 | 19.0 | 79.0 |
| | | % within true sex | 75.9% | 24.1% | 100.0% |
| | | % within predicted sex | 100.0% | 100.0% | 200.0% |
| | | % of total | 75.9% | 24.1% | 100.0% |

For males in age group 4 (17-19), an accurate prediction of sex in the CBCT sample occurred 6 (85.7%) times out of 7, while for females accurate prediction occurred 10 (66.7%) times out of 15 (Table 4.16). In total, 16 out of 22 cases were correctly sexed, with an overall accuracy of 72.7%. When using the posterior lateral angle, accurate sex prediction occurred 13 times (86.7%) out of 15 in females and 0 (0%) times out of 7 in males (Table 4.17). In total, 13 out of 22 cases were correctly sexed, with a lower overall accuracy of 59.0%.

Table 4.15

*Descriptive Statistics for the Left Lateral Angle in Group 4 (age 17-19)*

| | Side | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Ant LA | Left | 22 | 46.56364 | 9.134577 | 1.993328 |
| Post LA | Left | 22 | 56.12273 | 10.09487 | 2.20288 |

Table 4.16

*Sex Predictive Value of Noren et al.'s (2005) Lateral Angle Sectioning Point Using Anterior Lateral Angle Measurements in Age Group 4 (Age 17-19)*

| | | | Predicted Sex | | |
|---|---|---|---|---|---|
| | | | Female | Male | Total |
| True Sex | F | Count | 10 | 5 | 15 |
| | | Expected Count | 7.5 | 7.5 | 15.0 |
| | | % within true sex | 66.7% | 33.3% | 100.0% |
| | | % within predicted sex | 90.9% | 33.3% | 68.2% |
| | | % of total | 45.5% | 22.7% | 68.2% |
| | M | Count | 1 | 6 | 7 |
| | | Expected Count | 3.5 | 3.5 | 7.0 |
| | | % within true sex | 14.3% | 85.7% | 100.0% |
| | | % within predicted sex | 9.1% | 54.5% | 31.8% |
| | | % of total | 4.5% | 27.3% | 31.8% |
| Total | | Count | 11 | 11 | 22 |
| | | Expected Count | 11.0 | 11.0 | 22.0 |
| | | % within true sex | 50.0% | 50.0% | 100.0% |
| | | % within predicted sex | 100.0% | 100.0% | 200.0% |
| | | % of total | 50.0% | 50.0% | 100.0% |

Table 4.17

*Sex Predictive Value of Noren et al.'s (2005) Lateral Angle Sectioning Point Using Posterior Lateral Angle Measurements in Age Group 4 (Age 17-19)*

| | | | Predicted Sex | | |
|---|---|---|---|---|---|
| | | | Female | Male | Total |
| True Sex | F | Count | 13 | 2 | 15 |
| | | Expected Count | 13.6 | 1.4 | 15.0 |
| | | % within true sex | 86.7% | 13.3% | 100.0% |
| | | % within predicted sex | 65.0% | 13.3% | 68.2% |
| | | % of total | 59.1% | 9.1% | 68.2% |
| | M | Count | 7 | 0 | 7 |
| | | Expected Count | 6.4 | 0.6 | 7.0 |
| | | % within true sex | 100.0% | 0.0% | 100.0% |
| | | % within predicted sex | 35.0% | 0.0% | 31.8% |
| | | % of total | 31.8% | 0.0% | 31.8% |
| Total | | Count | 20 | 2 | 22 |
| | | Expected Count | 20.0 | 2.0 | 22.0 |
| | | % within true sex | 90.9% | 9.1% | 100.0% |
| | | % within predicted sex | 100.0% | 100.0% | 200.0% |
| | | % of total | 90.9% | 9.1% | 100.0% |

For males in age group 5 (20-24), an accurate prediction of sex in the CBCT sample occurred 3 (60.0%) times out of 5, while for females accurate prediction occurred 3 (30.0%) times out of 10 (Table 4.19). In total, 6 out of 15 cases were correctly sexed, with an overall accuracy of 40.0%. When using the posterior lateral angle, accurate sex prediction occurred 4 times (40.0%) out of 10 in females and 2 (40.0%) times out of 5 in males (Table 4.20). In total, 6 out of 15 cases were correctly sexed, with an overall accuracy of 40%.

Table 4.18

*Descriptive Statistics for the Left Lateral Angle in Group 5 (age 20-24)*

| | Side | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Ant LA | Left | 15 | 44.44 | 8.70408 | 2.32626 |
| Post LA | Left | 15 | 48.1267 | 8.37779 | 2.23906 |

Table 4.19

*Sex Predictive Value of Noren et al.'s (2005) Lateral Angle Sectioning Point Using Anterior Lateral Angle Measurements in Age Group 5 (Age 20-24)*

| | | | Predicted Sex | | |
|---|---|---|---|---|---|
| | | | Female | Male | Total |
| True Sex | F | Count | 3 | 7 | 10 |
| | | Expected Count | 3.3 | 6.7 | 10.0 |
| | | % within true sex | 30.0% | 70.0% | 100.0% |
| | | % within predicted sex | 60.0% | 70.0% | 66.7% |
| | | % of total | 20.0% | 46.7% | 66.7% |
| | M | Count | 2 | 3 | 5 |
| | | Expected Count | 1.7 | 3.3 | 5.0 |
| | | % within true sex | 40.0% | 60.0% | 100.0% |
| | | % within predicted sex | 40.0% | 30.0% | 33.3% |
| | | % of total | 13.3% | 20.0% | 33.3% |
| Total | | Count | 5 | 10 | 15 |
| | | Expected Count | 5.0 | 10.0 | 15.0 |
| | | % within true sex | 33.3% | 66.7% | 100.0% |
| | | % within predicted sex | 100.0% | 100.0% | 200.0% |
| | | % of total | 33.3% | 66.7% | 100.0% |

Table 4.20

*Sex Predictive Value of Noren et al.'s (2005) Lateral Angle Sectioning Point Using Posterior Lateral Angle Measurements in Age Group 5 (Age 20-24)*

| | | | Predicted Sex | | |
|---|---|---|---|---|---|
| | | | Female | Male | Total |
| True Sex | F | Count | 4 | 6 | 10 |
| | | Expected Count | 4.7 | 5.3 | 10.0 |
| | | % within true sex | 40.0% | 60.0% | 100.0% |
| | | % within predicted sex | 57.1% | 60.0% | 66.7% |
| | | % of total | 26.7% | 40.0% | 66.7% |
| | M | Count | 3 | 2 | 5 |
| | | Expected Count | 2.3 | 2.7 | 5.0 |
| | | % within true sex | 60.0% | 40.0% | 100.0% |
| | | % within predicted sex | 42.9% | 25.0% | 33.3% |
| | | % of total | 20.0% | 13.3% | 33.3% |
| Total | | Count | 7 | 8 | 15 |
| | | Expected Count | 7.0 | 8.0 | 15.0 |
| | | % within true sex | 46.7% | 53.3% | 100.0% |
| | | % within predicted sex | 100.0% | 100.0% | 200.0% |
| | | % of total | 46.7% | 53.3% | 100.0% |

Since the predictive value of Noren et al.'s (2005) 45° sectioning point for the sample of individuals examined in the present study was not always reliable, an independent-samples t test was carried out for each age group in order to analyze any potential sex differences in the anterior and posterior lateral angle for the data used in this study. No statistically significant differences were found between males and females in either anterior or posterior lateral angles within any age group (Table 4.21, Table 4.22, Table 4.23, Table 4.24, and Table 4.25).

Table 4.21

*Comparing the Anterior and Posterior Lateral Angle within Age Group 1 (Age 6-10)*

| | Gender | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Ant LA | Female | 39 | 46.4974 | 10.27128 | 1.64472 |
| | Male | 12 | 41.9333 | 7.48676 | 2.16124 |
| Post LA | Female | 39 | 52.1308 | 9.97627 | 1.59748 |
| | Male | 12 | 48.1583 | 10.25675 | 2.96087 |

*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 Difference | Std. Error Difference | Lower | Upper |
| Ant LA | Equal variances assumed | 3.705 | .060 | 1.423 | 49 | .161 | 4.56410 | 3.20734 | -1.88129 | 11.00950 |
| | Equal variances not assumed | | | 1.681 | 25.003 | .105 | 4.56410 | 2.71589 | -1.02935 | 10.15755 |
| Post LA | Equal variances assumed | .004 | .950 | 1.199 | 49 | .236 | 3.97244 | 3.31430 | -2.68790 | 10.63278 |
| | Equal variances not assumed | | | 1.181 | 17.897 | .253 | 3.97244 | 3.36432 | -3.09866 | 11.04353 |

Table 4.22

*Comparing the Anterior and Posterior Lateral Angle within Age Group 2 (Age 11-13)*

| | Gender | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Ant LA | Female | 59 | 45.9746 | 9.81497 | 1.27780 |
| | Male | 50 | 45.2900 | 11.89638 | 1.68240 |
| Post LA | Female | 59 | 53.0788 | 11.04469 | 1.43790 |
| | Male | 50 | 50.6040 | 11.07193 | 1.56581 |

*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 Difference | Std. Error Difference | Lower | Upper |
| Ant LA | Equal variances assumed | 2.198 | .141 | .329 | 107 | .743 | .68458 | 2.07945 | -3.4377 | 4.80683 |
| | Equal variances not assumed | | | .324 | 95.102 | .747 | .68458 | 2.11264 | -3.5095 | 4.87864 |
| Post LA | Equal variances assumed | .024 | .877 | 1.164 | 107 | .247 | 2.47481 | 2.12543 | -1.7386 | 6.68823 |
| | Equal variances not assumed | | | 1.164 | 104.004 | .247 | 2.47481 | 2.12586 | -1.7409 | 6.69048 |

Table 4.23

*Comparing the Anterior and Posterior Lateral Angle within Age Group 3 (Age 14-16)*

| | Gender | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Ant LA | Female | 42 | 49.5976 | 10.06240 | 1.55266 |
| | Male | 37 | 45.2081 | 10.84073 | 1.78220 |
| Post LA | Female | 42 | 54.9005 | 10.73307 | 1.65615 |
| | Male | 37 | 50.8027 | 11.44381 | 1.88135 |

*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 Difference | Std. Error Difference | Lower | Upper |
| Ant LA | Equal variances assumed | .131 | .718 | 1.866 | 77 | .066 | 4.38951 | 2.35244 | -.29480 | 9.07382 |
| | Equal variances not assumed | | | 1.857 | 73.970 | .067 | 4.38951 | 2.36369 | -.32027 | 9.09929 |
| Post LA | Equal variances assumed | .195 | .660 | 1.642 | 77 | .105 | 4.09777 | 2.49618 | -.87277 | 9.06831 |
| | Equal variances not assumed | | | 1.635 | 74.258 | .106 | 4.09777 | 2.50645 | -.89616 | 9.09170 |

Table 4.24

*Comparing the Anterior and Posterior Lateral Angle within Age Group 4 (Age 17-19)*

| | Gender | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Ant LA | Female | 15 | 47.9133 | 10.74476 | 2.77428 |
| | Male | 7 | 43.6714 | 4.71724 | 1.78295 |
| Post LA | Female | 15 | 55.9000 | 12.25159 | 3.16335 |
| | Male | 7 | 56.6000 | 4.79896 | 1.81384 |

*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 Difference | Std. Error Difference | Lower | Upper |
| Ant LA | Equal variances assumed | 2.755 | .113 | .991 | 20 | .334 | 4.24190 | 4.28151 | -4.68918 | 13.17299 |
| | Equal variances not assumed | | | 1.286 | 19.994 | .213 | 4.24190 | 3.29781 | -2.63734 | 11.12115 |
| Post LA | Equal variances assumed | 3.659 | .070 | -.145 | 20 | .887 | -.70000 | 4.84381 | -10.8040 | 9.40401 |
| | Equal variances not assumed | | | -.192 | 19.740 | .850 | -.70000 | 3.64647 | -8.31283 | 6.91283 |

Table 4.25

*Comparing the Anterior and Posterior Lateral Angle within Age Group 5 (Age 20-24)*

| | Gender | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Ant LA | Female | 10 | 45.1200 | 10.71435 | 3.38818 |
| | Male | 5 | 43.0800 | 4.72673 | 2.11386 |
| Post LA | Female | 10 | 48.4600 | 9.97332 | 3.15384 |
| | Male | 5 | 47.4600 | 6.21031 | 2.77734 |

*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 Difference | Std. Error Difference | Lower | Upper |
| Ant LA | Equal variances assumed | 1.752 | .208 | .401 | 13 | .695 | 2.04000 | 5.08968 | -8.95559 | 13.03559 |
| | Equal variances not assumed | | | .511 | 12.954 | .618 | 2.04000 | 3.99351 | -6.59057 | 10.67057 |
| Post LA | Equal variances assumed | 4.695 | .049 | .203 | 13 | .842 | 1.00000 | 4.92125 | -9.63171 | 11.63171 |
| | Equal variances not assumed | | | .238 | 12.057 | .816 | 1.00000 | 4.20242 | -8.15149 | 10.15149 |

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 anterior and posterior lateral angle size and age. A Pearson's correlation coefficient indicated no significant linear relationship between age and anterior (*p=0*.444) or posterior (*p*=0.447) lateral angle when the sexes were combined, nor was there any difference when controlling for sex (Table 4.26).

Table 4.26

*Correlations between Lateral Angle Size and Age*

| True Sex | | | Age | Ant LA | Post LA |
|---|---|---|---|---|---|
| Males and Females Combined | Age | Pearson Correlation | 1 | .046 | .046 |
| | | Sig. (2-tailed) | | .444 | .447 |
| | | N | 276 | 276 | 276 |
| | Ant LA | Pearson Correlation | .046 | 1 | .658** |
| | | Sig. (2-tailed) | .444 | | .000 |
| | | N | 276 | 276 | 276 |
| | Post LA | Pearson Correlation | .046 | .658** | 1 |
| | | Sig. (2-tailed) | .447 | .000 | |
| | | N | 276 | 276 | 276 |
| Female | Age | Pearson Correlation | 1 | .055 | .038 |
| | | Sig. (2-tailed) | | .486 | .627 |
| | | N | 165 | 165 | 165 |
| | Ant LA | Pearson Correlation | .055 | 1 | .627** |
| | | Sig. (2-tailed) | .486 | | .000 |
| | | N | 165 | 165 | 165 |
| | Post LA | Pearson Correlation | .038 | .627** | 1 |
| | | Sig. (2-tailed) | .627 | .000 | |
| | | N | 165 | 165 | 165 |
| Male | Age | Pearson Correlation | 1 | .052 | .079 |
| | | Sig. (2-tailed) | | .588 | .409 |
| | | N | 111 | 111 | 111 |
| | Ant LA | Pearson Correlation | .052 | 1 | .692** |
| | | Sig. (2-tailed) | .588 | | .000 |
| | | N | 111 | 111 | 111 |
| | Post LA | Pearson Correlation | .079 | .692** | 1 |
| | | Sig. (2-tailed) | .409 | .000 | |
| | | N | 111 | 111 | 111 |

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

**. Correlation is significant at the 0.01 level (2-tailed).

## Diameter Method

In 2006, Lynnerup and his colleagues published several sectioning points for the diameter of the internal auditory canal based on the largest size round drill that could fit in the opening. They proposed that a diameter of less than 3 mm is indicative of females while a diameter greater than 3.5 mm is indicative of males. Similarly, for a separate set of sectioning points, a diameter of 2.5 mm indicates a female while 4.0-4.5 mm indicates a male, and a diameter greater than 5.0 mm was undecided. Similar to Morgan's study in 2009, sex could not be accurately predicted in any of the cases used in this study since the majority of diameter measurements fell above 5.0 mm. Summary statistics for the diameter of the canal opening at 2 mm, 4 mm, 6 mm, and 8 mm lateral to the opening of the internal auditory meatus are provided for each age group in Table 4.27, Table 4.28, Table 4.29, Table 4.30, Table 4.31.

Table 4.27

*Descriptive Statistics for the Lateral Angle Diameter in Age Group 1 (Age 6-10)*

| | Gender | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Diam 2 | Female | 32 | 9.4166 | 1.98279 | .35051 |
| | Male | 9 | 10.5289 | 2.97469 | .99156 |
| Diam 4 | Female | 38 | 7.7882 | 2.08870 | .33883 |
| | Male | 12 | 8.5442 | 2.62843 | .75876 |
| Diam 6 | Female | 32 | 6.8738 | 1.57534 | .27848 |
| | Male | 9 | 7.6422 | 1.97870 | .65957 |
| Diam 8 | Female | 16 | 6.1163 | 1.04561 | .26140 |
| | Male | 6 | 6.4900 | 1.14440 | .46720 |

Table 4.28

*Descriptive Statistics for the Lateral Angle Diameter in Age Group 2 (Age 11-13)*

| | Gender | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Diam 2 | Female | 47 | 8.8462 | 1.47282 | .21483 |
| | Male | 40 | 9.2397 | 1.40876 | .22275 |
| Diam 4 | Female | 59 | 7.5080 | 1.32641 | .17268 |
| | Male | 49 | 7.8316 | 1.46963 | .20995 |
| Diam 6 | Female | 54 | 6.4715 | 1.02143 | .13900 |
| | Male | 43 | 7.1791 | 1.27597 | .19458 |
| Diam 8 | Female | 33 | 5.9218 | .80153 | .13953 |
| | Male | 24 | 7.7071 | 4.30441 | .87863 |

Table 4.29

*Descriptive Statistics for the Lateral Angle Diameter in Age Group 3 (Age 14-16)*

| | Gender | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Diam 2 | Female | 34 | 8.9091 | 1.73786 | .29804 |
| | Male | 32 | 9.5284 | 2.35297 | .41595 |
| Diam 4 | Female | 42 | 7.4755 | 1.52278 | .23497 |
| | Male | 36 | 7.8692 | 1.50772 | .25129 |
| Diam 6 | Female | 40 | 6.6623 | 1.30700 | .20666 |
| | Male | 35 | 7.2254 | 1.19603 | .20217 |
| Diam 8 | Female | 25 | 6.3072 | 1.19388 | .23878 |
| | Male | 20 | 7.1195 | 1.74998 | .39131 |

Table 4.30

*Descriptive Statistics for the Lateral Angle Diameter in Age Group 4 (Age 17-19)*

| | Gender | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Diam 2 | Female | 15 | 8.5007 | 1.64998 | .42602 |
| | Male | 6 | 9.2150 | 1.22658 | .50075 |
| Diam 4 | Female | 15 | 6.6820 | 1.12869 | .29143 |
| | Male | 7 | 7.7786 | 1.15006 | .43468 |
| Diam 6 | Female | 15 | 5.9407 | .74597 | .19261 |
| | Male | 7 | 6.7514 | .91576 | .34612 |
| Diam 8 | Female | 11 | 5.7636 | .93078 | .28064 |
| | Male | 6 | 6.2900 | .59313 | .24214 |

Table 4.31

*Descriptive Statistics for the Lateral Angle Diameter in Age Group 5 (Age 20-24)*

| | Gender | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Diam 2 | Female | 10 | 8.4260 | 2.39999 | .75894 |
| | Male | 5 | 9.8180 | .99547 | .44519 |
| Diam 4 | Female | 10 | 6.9700 | 1.23603 | .39087 |
| | Male | 5 | 7.8820 | .95043 | .42505 |
| Diam 6 | Female | 8 | 5.9212 | .68657 | .24274 |
| | Male | 5 | 7.4480 | .41493 | .18556 |
| Diam 8 | Female | 3 | 5.2500 | .89867 | .51884 |
| | Male | 2 | 6.6950 | .45962 | .32500 |

Since the drills used by Lynnerup (2006) had diameters that increased in 0.5 mm increments, the diameters measured from the current sample were rounded from 2 decimal places to 0.5 mm increments and were placed into frequency tables to analyze the distribution of the diameters between the sexes (Table 4.32, Table 4.33, Table 4.34, and Table 4.35 and Figure 4.1, Figure 4.2, Figure 4.3, and Figure 4.4.)

Table 4.32

*Frequency Table for the Diameter at 2 mm (0.5 mm)*

| mm | Female | Percent | mm | Male | Percent |
|---|---|---|---|---|---|
| 9.5 | 14 | 8.5 | 9.5 | 9 | 8.1 |
| 9 | 15 | 9.1 | 9 | 12 | 10.8 |
| 8.5 | 10 | 6.1 | 8.5 | 10 | 9.0 |
| 8 | 18 | 10.9 | 8 | 12 | 10.8 |
| 7.5 | 10 | 6.1 | 7.5 | 8 | 7.2 |
| 7 | 13 | 7.9 | 6.5 | 1 | .9 |
| 6.5 | 5 | 3.0 | 6 | 2 | 1.8 |
| 6 | 5 | 3.0 | 5.5 | 2 | 1.8 |
| 5.5 | 2 | 1.2 | 17 | 1 | .9 |
| 5 | 1 | .6 | 14 | 2 | 1.8 |
| 14 | 1 | .6 | 13 | 2 | 1.8 |
| 13.5 | 1 | .6 | 12.5 | 2 | 1.8 |
| 13 | 1 | .6 | 12 | 2 | 1.8 |
| 12.5 | 1 | .6 | 11.5 | 7 | 6.3 |
| 12 | 4 | 2.4 | 11 | 8 | 7.2 |
| 11.5 | 4 | 2.4 | 10.5 | 4 | 3.6 |
| 11 | 13 | 7.9 | 10 | 8 | 7.2 |
| 10.5 | 6 | 3.6 | Total | 111 | 100.0 |
| 10 | 14 | 8.5 | | | |
| *Total* | 165 | 100.0 | | | |

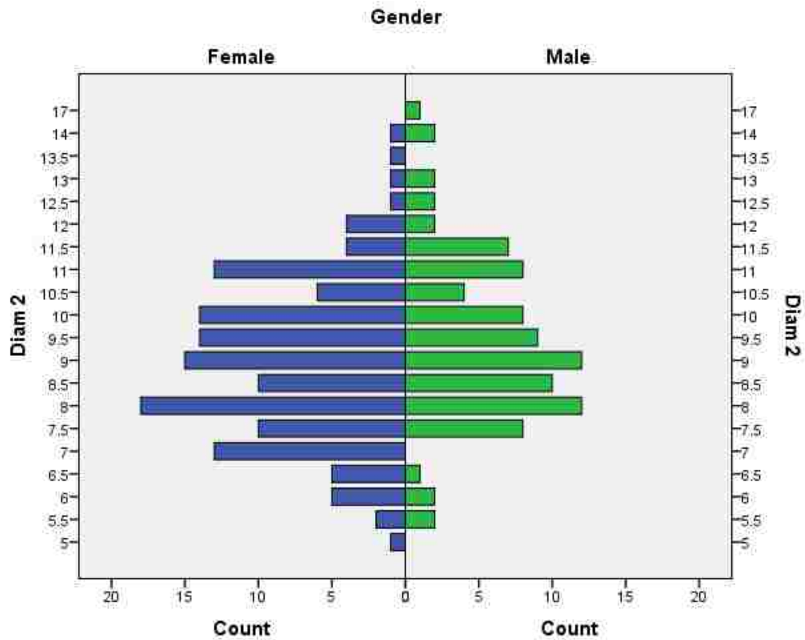



*Figure 4.1*. Histogram illustrating distribution of diameter at 2 mm (0.5 mm) in males and females

Table 4.33

*Frequency Table for the Diameter at 4 mm (0.5 mm)*

| mm | Female | Percent | mm | Male | Percent |
|---|---|---|---|---|---|
| 9.5 | 2 | 1.2 | 9.5 | 4 | 3.6 |
| 9 | 8 | 4.8 | 9 | 5 | 4.5 |
| 8.5 | 16 | 9.7 | 8.5 | 16 | 14.4 |
| 8 | 11 | 6.7 | 8 | 11 | 9.9 |
| 7.5 | 23 | 13.9 | 7.5 | 16 | 14.4 |
| 7 | 32 | 19.4 | 7 | 13 | 11.7 |
| 6.5 | 23 | 13.9 | 6.5 | 16 | 14.4 |
| 6 | 22 | 13.3 | 6 | 10 | 9.0 |
| 5.5 | 5 | 3.0 | 5.5 | 3 | 2.7 |
| 5 | 5 | 3.0 | 13 | 2 | 1.8 |
| 4.5 | 1 | .6 | 12.5 | 2 | 1.8 |
| 16 | 1 | .6 | 11.5 | 1 | .9 |
| 12 | 1 | .6 | 11 | 1 | .9 |
| 11.5 | 1 | .6 | 10.5 | 2 | 1.8 |
| 11 | 2 | 1.2 | 10 | 7 | 6.3 |
| 10.5 | 5 | 3.0 | Total | 111 | 100.0 |
| 10 | 6 | 3.6 | | | |
| Total | 165 | 100.0 | | | |

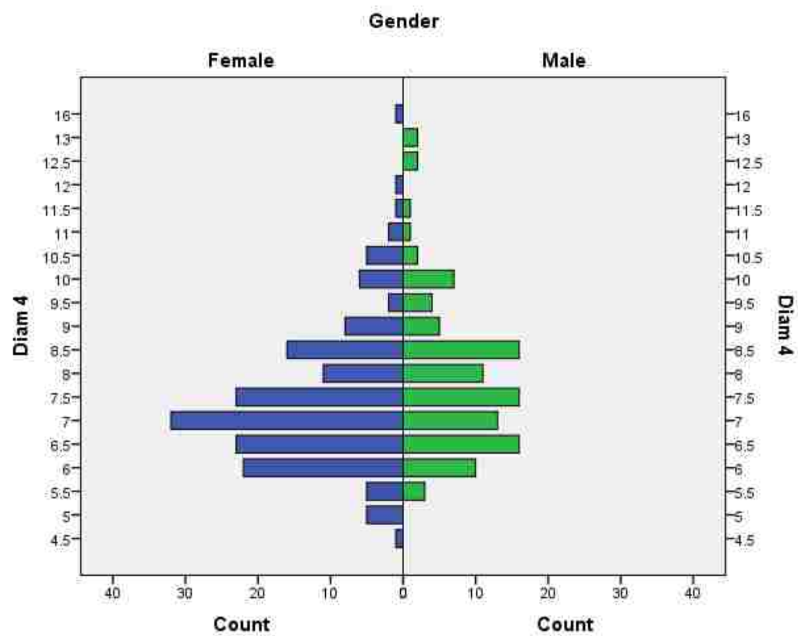



*Figure 4.2.* Histogram illustrating distribution of diameter at 4 mm (0.5 mm) in males and females

Table 4.34

*Frequency Table for the Diameter at 6 mm (0.5 mm)*

| mm | Female | Percent | mm | Male | Percent |
|---|---|---|---|---|---|
| 9 | 3 | 1.8 | 9.5 | 2 | 1.8 |
| 8.5 | 3 | 1.8 | 9 | 5 | 4.5 |
| 8 | 9 | 5.5 | 8.5 | 5 | 4.5 |
| 7.5 | 14 | 8.5 | 8 | 11 | 9.9 |
| 7 | 26 | 15.8 | 7.5 | 16 | 14.4 |
| 6.5 | 19 | 11.5 | 7 | 16 | 14.4 |
| 6 | 31 | 18.8 | 6.5 | 15 | 13.5 |
| 5.5 | 23 | 13.9 | 6 | 19 | 17.1 |
| 5 | 14 | 8.5 | 5.5 | 4 | 3.6 |
| 4.5 | 3 | 1.8 | 5 | 1 | .9 |
| 12 | 1 | .6 | 12 | 1 | .9 |
| 10.5 | 2 | 1.2 | 10.5 | 3 | 2.7 |
| 10 | 1 | .6 | 10 | 1 | .9 |
| Total | 165 | 100.0 | Total | 111 | 100.0 |

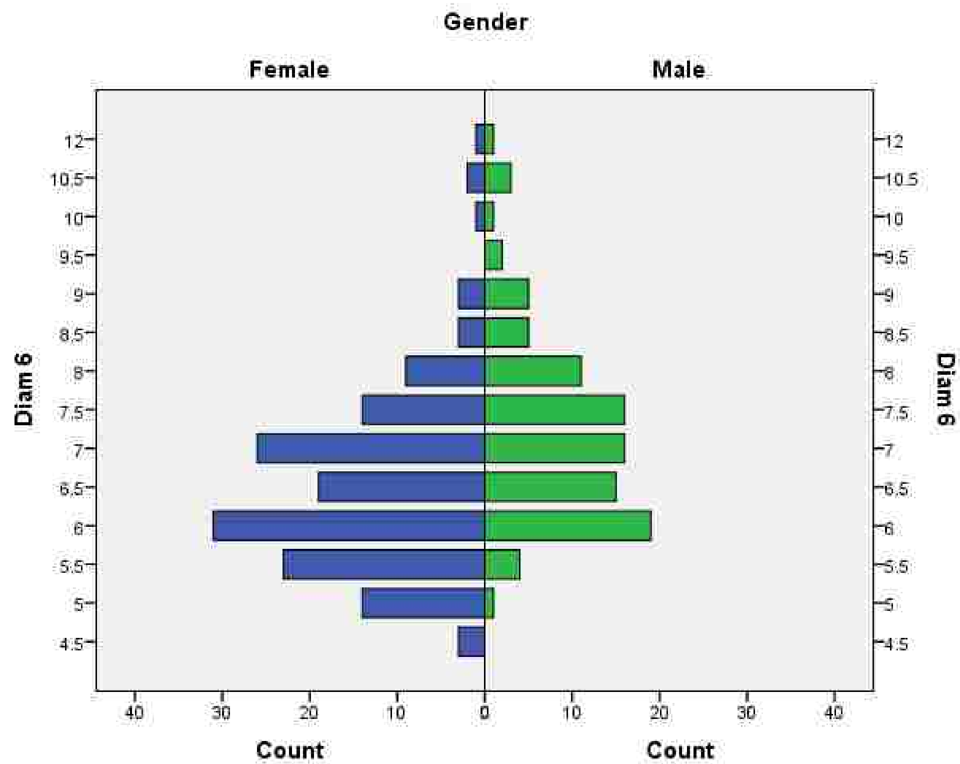



*Figure 4.3.* Histogram illustrating distribution of diameter at 6 mm (0.5 mm) in males and females

Table 4.35

*Frequency Table for the Diameter at 8 mm (0.5 mm)*

| mm | Female | Percent | mm | Male | Percent |
|---|---|---|---|---|---|
| 9.50 | 1 | .6 | 9.00 | 1 | .9 |
| 8.50 | 1 | .6 | 8.00 | 6 | 5.4 |
| 7.50 | 6 | 3.6 | 7.50 | 11 | 9.9 |
| 7.00 | 8 | 4.8 | 7.00 | 7 | 6.3 |
| 6.50 | 12 | 7.3 | 6.50 | 13 | 11.7 |
| 6.00 | 23 | 13.9 | 6.00 | 8 | 7.2 |
| 5.50 | 21 | 12.7 | 5.50 | 4 | 3.6 |
| 5.00 | 8 | 4.8 | 5.00 | 3 | 2.7 |
| 4.50 | 6 | 3.6 | 4.50 | 2 | 1.8 |
| 4.00 | 1 | .6 | 27.50 | 1 | .9 |
| 10.50 | 1 | .6 | 12.50 | 1 | .9 |
| Total | 165 | 100.0 | 10.00 | 1 | .9 |
| | | | Total | 111 | 100.0 |

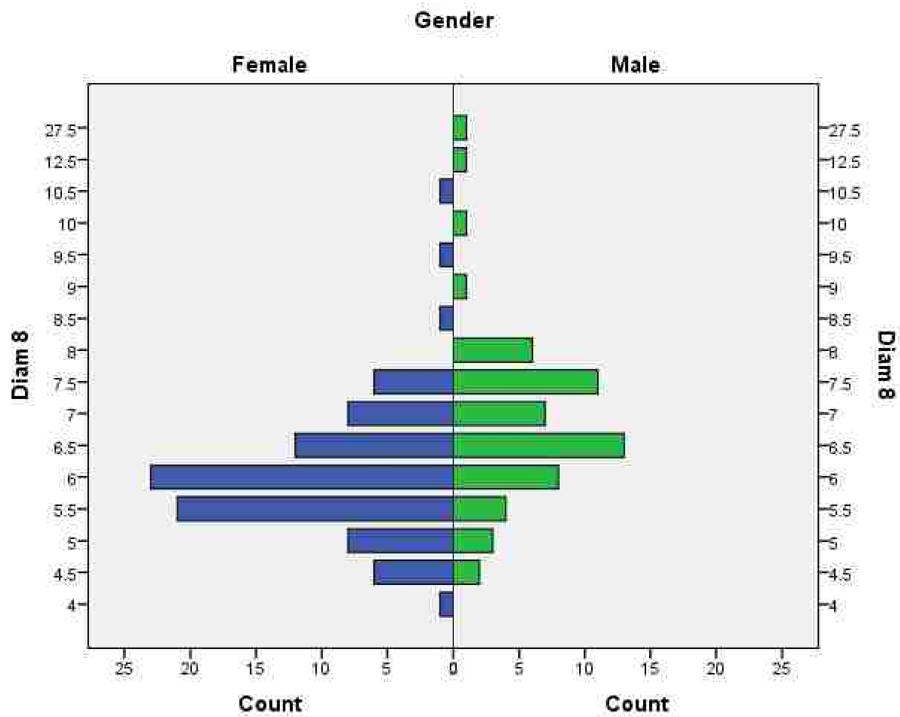



*Figure 4.4.* Histogram illustrating distribution of diameter at 8 mm (0.5 mm) in males and females

Independent samples t tests were also conducted for each of the four diameter measures to determine whether or not significant sex differences exist in diameter size for the current CBCT sample. In age group 1, there was no significant difference between males and females for measurements in diameter at 2 mm ($p$ = .192), 4 mm ($p$ = .310), 6 mm (p = .229), or 8 mm (p = .475) from the internal auditory meatus (Table 4.36). In age group 2, there was no significant difference between males and females for measurements in diameter at 2 mm (p = .209) and 4 mm (p = .232), while there was a statistically significant difference at 6 mm (p = .003) and 8 mm (p = .023) from the internal auditory meatus (Table 4.37). In age group 3, there was no significant difference between males and females for measurements in diameter at 2 mm ($p = .226$), 4 mm ($p = .256$), 6 mm ($p = .057$), or 8 mm ($p = .072$) from the internal auditory meatus (Table 4.38). In age group 4, there was no significant difference between males and females for measurements in diameter at 2 mm ($p = .352$) and 8 mm ($p = .253$), while there was a statistically significant difference at 4 mm ($p = .048$) and 6 mm ($p = .039$) from the internal auditory meatus (Table 4.39). In age group 5, there was no significant difference between males and females for measurements in diameter at 2 mm ($p = .242$), 4 mm ($p = .173$), and 8 mm ($p = .136$), while there was a statistically significant difference at 6 mm ($p = .001$) from the internal auditory meatus (Table 4.40).

Table 4.36

*Comparing the Diameter in Males vs. Females in Age Group 1 (Age 6-10)*

*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 Difference | Std. Error Difference | Lower | Upper |
| Diam 2 | Equal variances assumed | 2.048 | .160 | -1.326 | 39 | .192 | -1.11233 | .83862 | -2.80860 | .58394 |
| | Equal variances not assumed | | | -1.058 | 10.084 | .315 | -1.11233 | 1.05169 | -3.45301 | 1.22836 |
| Diam 4 | Equal variances assumed | 1.119 | .296 | -1.027 | 48 | .310 | -.75601 | .73644 | -2.23671 | .72470 |
| | Equal variances not assumed | | | -.910 | 15.640 | .377 | -.75601 | .83098 | -2.52091 | 1.00889 |
| Diam 6 | Equal variances assumed | 1.942 | .171 | -1.222 | 39 | .229 | -.76847 | .62862 | -2.03997 | .50303 |
| | Equal variances not assumed | | | -1.073 | 11.016 | .306 | -.76847 | .71595 | -2.34398 | .80703 |
| Diam 8 | Equal variances assumed | .915 | .350 | -.729 | 20 | .475 | -.37375 | .51278 | -1.44339 | .69589 |
| | Equal variances not assumed | | | -.698 | 8.348 | .504 | -.37375 | .53535 | -1.59938 | .85188 |

Table 4.37

*Comparing the Diameter in Males vs. Females in Age Group 2 (Age 11-13)*

*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 Difference | Std. Error Difference | Lower | Upper |
| Diam 2 | Equal variances assumed | .000 | .995 | -1.267 | 85 | .209 | -.39358 | .31059 | -1.01111 | .22395 |
| | Equal variances not assumed | | | -1.272 | 83.815 | .207 | -.39358 | .30947 | -1.00901 | .22185 |
| Diam 4 | Equal variances assumed | 1.442 | .232 | -1.202 | 106 | .232 | -.32367 | .26926 | -.85749 | .21016 |
| | Equal variances not assumed | | | -1.191 | 97.851 | .237 | -.32367 | .27184 | -.86314 | .21580 |
| Diam 6 | Equal variances assumed | .081 | .776 | -3.034 | 95 | .003 | -.70759 | .23320 | -1.17056 | -.24462 |
| | Equal variances not assumed | | | -2.959 | 79.414 | .004 | -.70759 | .23913 | -1.18353 | -.23165 |
| Diam 8 | Equal variances assumed | 3.243 | .077 | -2.335 | 55 | .023 | -1.78527 | .76454 | -3.31744 | -.25309 |
| | Equal variances not assumed | | | -2.007 | 24.164 | .056 | -1.78527 | .88964 | -3.62074 | .05021 |

Table 4.38

*Comparing the Diameter in Males vs. Females in Age Group 3 (Age 14-16)*

*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 Difference | Std. Error Difference | Lower | Upper |
| Diam 2 | Equal variances assumed | 3.112 | .082 | -1.221 | 64 | .226 | -.61932 | .50709 | -1.63236 | .39372 |
| | Equal variances not assumed | | | -1.210 | 56.911 | .231 | -.61932 | .51170 | -1.64403 | .40539 |
| Diam 4 | Equal variances assumed | .010 | .920 | -1.143 | 76 | .256 | -.39369 | .34430 | -1.07941 | .29203 |
| | Equal variances not assumed | | | -1.144 | 74.404 | .256 | -.39369 | .34403 | -1.07912 | .29174 |
| Diam 6 | Equal variances assumed | .005 | .943 | -1.936 | 73 | .057 | -.56318 | .29083 | -1.14281 | .01645 |
| | Equal variances not assumed | | | -1.948 | 72.842 | .055 | -.56318 | .28910 | -1.13937 | .01301 |
| Diam 8 | Equal variances assumed | .744 | .393 | -1.847 | 43 | .072 | -.81230 | .43975 | -1.69915 | .07455 |
| | Equal variances not assumed | | | -1.772 | 32.244 | .086 | -.81230 | .45841 | -1.74576 | .12116 |

Table 4.39

*Comparing the Diameter in Males vs. Females in Age Group 4 (Age 17-19)*

*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 Difference | Std. Error Difference | Lower | Upper |
| Diam 2 | Equal variances assumed | .590 | .452 | -.954 | 19 | .352 | -.71433 | .74863 | -2.28124 | .85257 |
| | Equal variances not assumed | | | -1.087 | 12.516 | .298 | -.71433 | .65746 | -2.14029 | .71162 |
| Diam 4 | Equal variances assumed | .029 | .867 | -2.110 | 20 | .048 | -1.09657 | .51960 | -2.18043 | -.01271 |
| | Equal variances not assumed | | | -2.095 | 11.601 | .059 | -1.09657 | .52333 | -2.24118 | .04804 |
| Diam 6 | Equal variances assumed | .534 | .473 | -2.212 | 20 | .039 | -.81076 | .36651 | -1.57529 | -.04624 |
| | Equal variances not assumed | | | -2.047 | 9.885 | .068 | -.81076 | .39611 | -1.69474 | .07321 |
| Diam 8 | Equal variances assumed | 1.530 | .235 | -1.244 | 15 | .233 | -.52636 | .42305 | -1.42807 | .37535 |
| | Equal variances not assumed | | | -1.420 | 14.433 | .177 | -.52636 | .37066 | -1.31913 | .26640 |

Table 4.40

*Comparing the Diameter in Males vs. Females in Age Group 5 (Age 20-24)*

*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 Difference | Std. Error Difference | Lower | Upper |
| Diam2 | Equal variances assumed | 2.903 | .112 | -1.23 | 13 | .242 | -1.39200 | 1.13480 | -3.844 | 1.0596 |
| | Equal variances not assumed | | | -1.58 | 12.839 | .138 | -1.39200 | .87988 | -3.295 | .51129 |
| Diam4 | Equal variances assumed | .121 | .733 | -1.44 | 13 | .173 | -.91200 | .63300 | -2.280 | .45552 |
| | Equal variances not assumed | | | -1.58 | 10.339 | .144 | -.91200 | .57744 | -2.193 | .36892 |
| Diam6 | Equal variances assumed | 1.170 | .303 | -4.45 | 11 | .001 | -1.52675 | .34328 | -2.282 | -.7712 |
| | Equal variances not assumed | | | -5.00 | 10.999 | .000 | -1.52675 | .30554 | -2.199 | -.8542 |
| Diam8 | Equal variances assumed | 1.491 | .309 | -2.03 | 3 | .136 | -1.44500 | .71228 | -3.712 | .82180 |
| | Equal variances not assumed | | | -2.36 | 2.965 | .100 | -1.44500 | .61223 | -3.407 | .51663 |

A Pearson's correlation analysis was conducted to determine if there was a relationship between age and the diameter of the internal auditory canal. When both sexes were combined, there was no relationship between age and the diameter at 2 mm ($p$ = .099), 6 mm ($p$ = .078), and 8 mm ($p$ = .944); however, there was a statistically significant ($p$ = .022) negative correlation between age and the diameter at 4 mm (Table 4.41 and Figure 4.5). When controlling for sex, there was a negative correlation between age and the diameter at 2 mm ($p$ = .045), 4 mm ($p$ = .033), and 6 mm ($p$ = .024) lateral to the internal auditory meatus in females (Table 4.42 and Figure 4.6, Figure 4.7, and Figure 4.8). This correlation was not statistically significant in males.

Table 4.41

*Correlation between the Diameter and Age in Males and Females*

| | | Age | Diam2 | Diam4 | Diam6 | Diam8 |
|---|---|---|---|---|---|---|
| Age | Pearson Correlation | 1 | -.109 | -.139* | -.112 | -.006 |
| | Sig. (2-tailed) | | .099 | .022 | .078 | .944 |
| | Sum of Squares and Cross-products | 2904.112 | -156.570 | -196.461 | -115.182 | -5.708 |
| | Covariance | 10.560 | -.684 | -.722 | -.466 | -.039 |
| | N | 276 | 230 | 273 | 248 | 146 |
| Diam2 | Pearson Correlation | -.109 | 1 | .695** | .521** | .134 |
| | Sig. (2-tailed) | .099 | | .000 | .000 | .168 |
| | Sum of Squares and Cross-products | -156.570 | 787.005 | 357.817 | 206.709 | 65.345 |
| | Covariance | -.684 | 3.437 | 1.563 | 1.023 | .616 |
| | N | 230 | 230 | 230 | 203 | 107 |
| Diam4 | Pearson Correlation | -.139* | .695** | 1 | .755** | .260** |
| | Sig. (2-tailed) | .022 | .000 | | .000 | .002 |
| | Sum of Squares and Cross-products | -196.461 | 357.817 | 696.079 | 360.121 | 139.523 |
| | Covariance | -.722 | 1.563 | 2.559 | 1.476 | .976 |
| | N | 273 | 230 | 273 | 245 | 144 |
| Diam6 | Pearson Correlation | -.112 | .521** | .755** | 1 | .381** |
| | Sig. (2-tailed) | .078 | .000 | .000 | | .000 |
| | Sum of Squares and Cross-products | -115.182 | 206.709 | 360.121 | 409.026 | 159.561 |
| | Covariance | -.466 | 1.023 | 1.476 | 1.656 | 1.140 |
| | N | 248 | 203 | 245 | 248 | 141 |
| Diam8 | Pearson Correlation | -.006 | .134 | .260** | .381** | 1 |
| | Sig. (2-tailed) | .944 | .168 | .002 | .000 | |
| | Sum of Squares and Cross-products | -5.708 | 65.345 | 139.523 | 159.561 | 642.233 |
| | Covariance | -.039 | .616 | .976 | 1.140 | 4.429 |
| | N | 146 | 107 | 144 | 141 | 146 |

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

**. Correlation is significant at the 0.01 level (2-tailed).

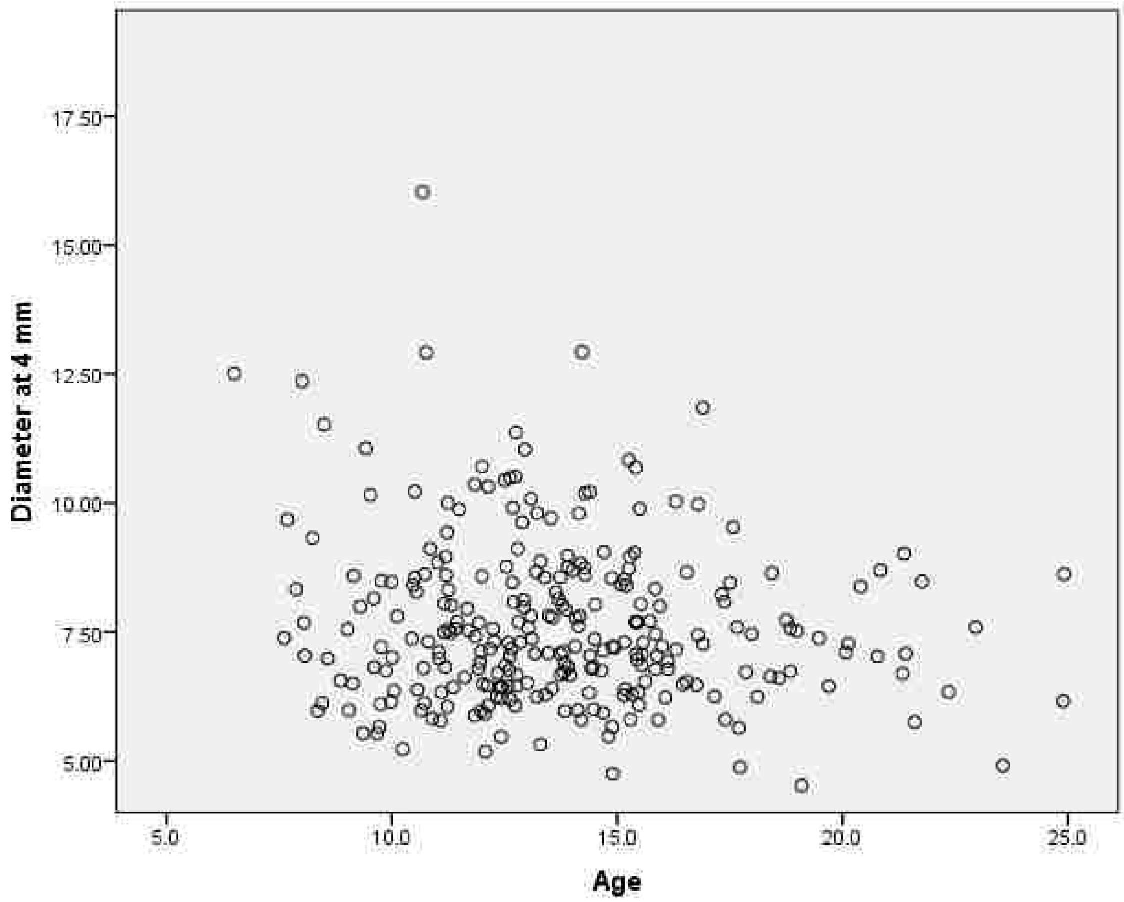



*Figure 4.5.* Scatterplot of the correlation between the diameter at 4 mm and age in males and females

Table 4.42

*Correlation between the Diameter and Age in Males vs. Females*

| Gender | | | Age | Diam2 | Diam4 | Diam6 | Diam8 |
|---|---|---|---|---|---|---|---|
| *Female* | Age | Pearson Correlation | 1 | -.171* | -.166* | -.185* | -.073 |
| | | Sig. (2-tailed) | | .045 | .033 | .024 | .499 |
| | | N | 165 | 138 | 164 | 149 | 88 |
| | Diam2 | Pearson Correlation | -.171* | 1 | .700** | .561** | .264* |
| | | Sig. (2-tailed) | .045 | | .000 | .000 | .033 |
| | | N | 138 | 138 | 138 | 123 | 65 |
| | Diam4 | Pearson Correlation | -.166* | .700** | 1 | .780** | .547** |
| | | Sig. (2-tailed) | .033 | .000 | | .000 | .000 |
| | | N | 164 | 138 | 164 | 148 | 88 |
| | Diam6 | Pearson Correlation | -.185* | .561** | .780** | 1 | .759** |
| | | Sig. (2-tailed) | .024 | .000 | .000 | | .000 |
| | | N | 149 | 123 | 148 | 149 | 86 |
| | Diam8 | Pearson Correlation | -.073 | .264* | .547** | .759** | 1 |
| | | Sig. (2-tailed) | .499 | .033 | .000 | .000 | |
| | | N | 88 | 65 | 88 | 86 | 88 |
| *Male* | Age | Pearson Correlation | 1 | -.043 | -.118 | -.067 | .008 |
| | | Sig. (2-tailed) | | .682 | .223 | .509 | .951 |
| | | N | 111 | 92 | 109 | 99 | 58 |
| | Diam2 | Pearson Correlation | -.043 | 1 | .671** | .397** | .069 |
| | | Sig. (2-tailed) | .682 | | .000 | .000 | .665 |
| | | N | 92 | 92 | 92 | 80 | 42 |
| | Diam4 | Pearson Correlation | -.118 | .671** | 1 | .693** | .128 |
| | | Sig. (2-tailed) | .223 | .000 | | .000 | .348 |
| | | N | 109 | 92 | 109 | 97 | 56 |
| | Diam6 | Pearson Correlation | -.067 | .397** | .693** | 1 | .160 |
| | | Sig. (2-tailed) | .509 | .000 | .000 | | .243 |
| | | N | 99 | 80 | 97 | 99 | 55 |
| | Diam8 | Pearson Correlation | .008 | .069 | .128 | .160 | 1 |
| | | Sig. (2-tailed) | .951 | .665 | .348 | .243 | |
| | | N | 58 | 42 | 56 | 55 | 58 |

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

**. Correlation is significant at the 0.01 level (2-tailed).

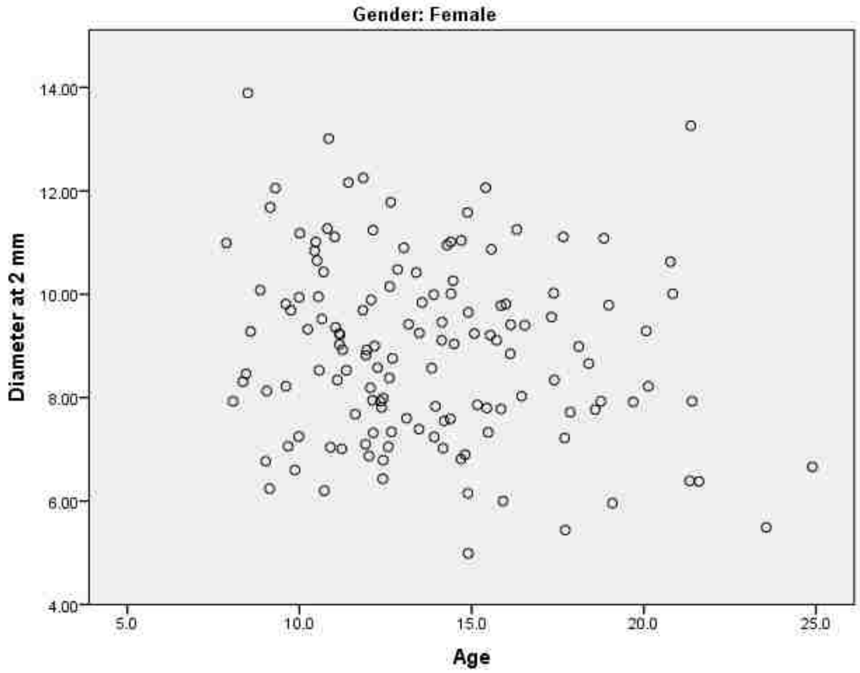



*Figure 4.6.* Scatterplot of the correlation between the diameter at 2 mm and age in females

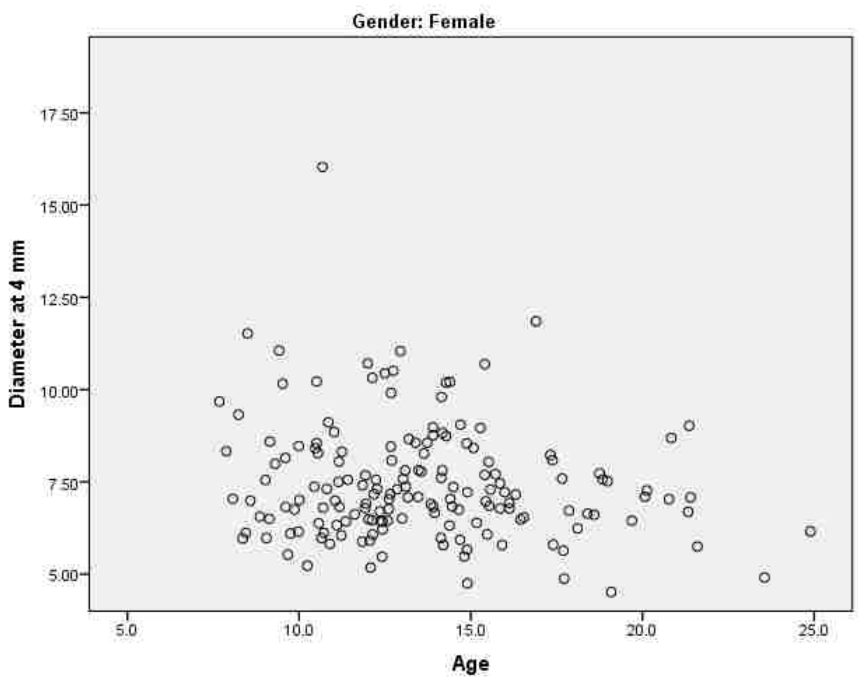



*Figure 4.7.* Scatterplot of the correlation between the diameter at 4 mm and age in females

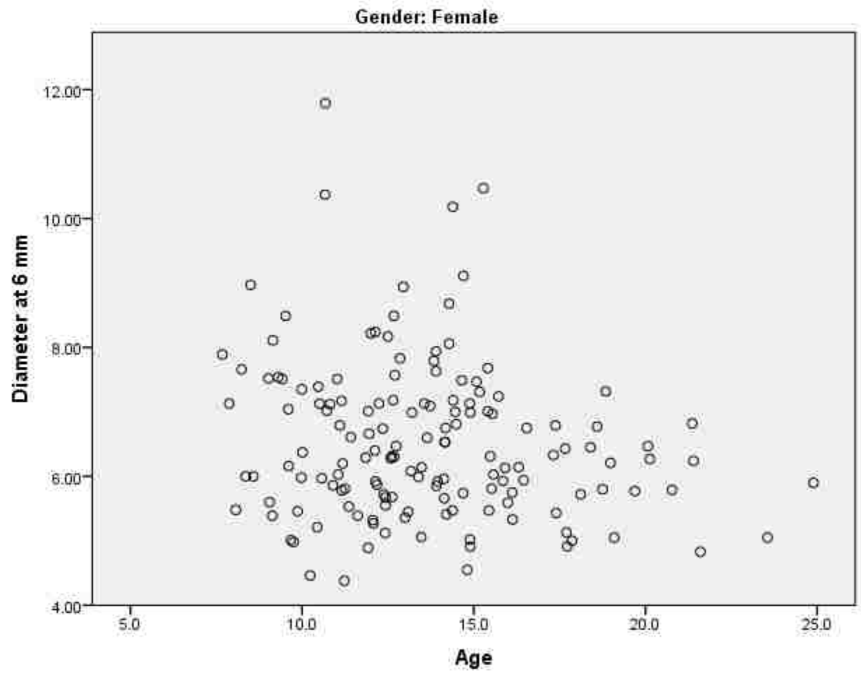



*Figure 4.8.* Scatterplot of the correlation between the diameter at 6 mm and age in females

## The Area Method

No published sectioning points were provided in the literature on the cross-sectional area of the internal auditory canal; thus predictive values for sex using those areas could not be determined from previous research studies. Descriptive statistics for the cross-sectional area at 2 mm, 4 mm, 6 mm, and 8 mm lateral to the internal auditory meatus are provided in (Table 4.43, Table 4.44, Table 4.45, Table 4.46, Table 4.47).

Table 4.43

*Descriptive Statistics for the Cross-Sectional Area in Males vs. Females in Age Group 1 (Age 6-10)*

| | Gender | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Area 2 | Female | 32 | 33.7784 | 12.72901 | 2.25019 |
| | Male | 9 | 42.6233 | 20.59297 | 6.86432 |
| Area 4 | Female | 38 | 30.8071 | 11.78730 | 1.91215 |
| | Male | 12 | 36.7242 | 17.88664 | 5.16343 |
| Area 6 | Female | 32 | 28.7028 | 9.52915 | 1.68453 |
| | Male | 9 | 33.3211 | 13.99967 | 4.66656 |
| Area 8 | Female | 16 | 24.7631 | 6.61526 | 1.65381 |
| | Male | 6 | 25.3100 | 7.44171 | 3.03807 |

Table 4.44

*Descriptive Statistics for the Cross-Sectional Area in Males vs. Females in Age Group 2 (Age 11-13)*

| | Gender | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Area 2 | Female | 47 | 30.0809 | 7.69627 | 1.12262 |
| | Male | 40 | 34.2340 | 11.17851 | 1.76748 |
| Area 4 | Female | 59 | 27.6975 | 7.98517 | 1.03958 |
| | Male | 49 | 31.7114 | 11.94134 | 1.70591 |
| Area 6 | Female | 54 | 26.2196 | 7.41257 | 1.00872 |
| | Male | 43 | 30.7753 | 8.77474 | 1.33814 |
| Area 8 | Female | 33 | 23.2345 | 5.56958 | .96954 |
| | Male | 24 | 29.7746 | 8.98914 | 1.83490 |

Table 4.45

*Descriptive Statistics for the Cross-Sectional Area in Males vs. Females in Age Group 3 (Age 14-16)*

| | Gender | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Area 2 | Female | 34 | 29.7909 | 11.04958 | 1.89499 |
| | Male | 32 | 35.9581 | 10.73498 | 1.89769 |
| Area 4 | Female | 42 | 27.1590 | 9.40925 | 1.45188 |
| | Male | 36 | 31.4261 | 9.10725 | 1.51788 |
| Area 6 | Female | 40 | 27.9803 | 10.61380 | 1.67819 |
| | Male | 35 | 30.4191 | 7.22901 | 1.22193 |
| Area 8 | Female | 25 | 26.7180 | 7.78119 | 1.55624 |
| | Male | 20 | 30.6080 | 9.17295 | 2.05113 |

Table 4.46

*Descriptive Statistics for the Cross-Sectional Area in Males vs. Females in Age Group 4 (Age 17-19)*

| | Gender | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Area 2 | Female | 15 | 27.7893 | 6.92254 | 1.78739 |
| | Male | 6 | 33.3167 | 7.54102 | 3.07861 |
| Area 4 | Female | 15 | 22.8973 | 6.53584 | 1.68755 |
| | Male | 7 | 29.0857 | 7.74708 | 2.92812 |
| Area 6 | Female | 15 | 21.6407 | 6.36576 | 1.64363 |
| | Male | 7 | 30.3486 | 8.30980 | 3.14081 |
| Area 8 | Female | 11 | 21.0027 | 5.57185 | 1.67998 |
| | Male | 6 | 27.4367 | 6.07498 | 2.48010 |

Table 4.47

*Descriptive Statistics for the Cross-Sectional Area in Males vs. Females in Age Group 5 (Age 20-24)*

| | Gender | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Area 2 | Female | 10 | 28.6300 | 11.30412 | 3.57468 |
| | Male | 5 | 31.1940 | 4.35390 | 1.94713 |
| Area 4 | Female | 10 | 24.8460 | 7.77837 | 2.45974 |
| | Male | 5 | 26.5160 | 3.81755 | 1.70726 |
| Area 6 | Female | 8 | 22.0787 | 5.58871 | 1.97591 |
| | Male | 5 | 28.1820 | 4.69287 | 2.09872 |
| Area 8 | Female | 3 | 21.2967 | 8.13674 | 4.69775 |
| | Male | 2 | 26.4850 | .17678 | .12500 |

After rounding from two decimal places to the nearest whole number, the cross-sectional areas at 2 mm, 4 mm, 6 mm, and 8 mm were placed into frequency tables and histograms to analyze size distributions within each sex (Table 4.48, Table 4.49, Table 4.50, Table 4.51, and Figure 4.9, Figure 4.10, Figure 4.11, and Figure 4.12).

Table 4.48

*Frequency Table for Cross-Sectional Area at 2 mm in Males vs. Females*

| Females | | | Males | | |
|---|---|---|---|---|---|
| | Frequency | Valid Percent | $mm^2$ | Frequency | Valid Percent |
| 13 | 1 | .7 | 16 | 1 | 1.1 |
| 14 | 3 | 2.2 | 19 | 1 | 1.1 |
| 15 | 1 | .7 | 20 | 1 | 1.1 |
| 16 | 1 | .7 | 21 | 4 | 4.3 |
| 17 | 1 | .7 | 22 | 2 | 2.2 |
| 18 | 2 | 1.4 | 23 | 1 | 1.1 |
| 19 | 4 | 2.9 | 24 | 1 | 1.1 |
| 20 | 3 | 2.2 | 25 | 5 | 5.4 |
| 21 | 4 | 2.9 | 26 | 6 | 6.5 |
| 22 | 8 | 5.8 | 27 | 1 | 1.1 |
| 23 | 5 | 3.6 | 28 | 6 | 6.5 |
| 24 | 10 | 7.2 | 29 | 1 | 1.1 |
| 25 | 6 | 4.3 | 30 | 2 | 2.2 |
| 26 | 4 | 2.9 | 31 | 3 | 3.3 |
| 27 | 7 | 5.1 | 32 | 5 | 5.4 |
| 28 | 5 | 3.6 | 33 | 8 | 8.7 |
| 29 | 5 | 3.6 | 35 | 10 | 10.9 |
| 30 | 9 | 6.5 | 36 | 3 | 3.3 |
| 31 | 6 | 4.3 | 38 | 2 | 2.2 |
| 32 | 8 | 5.8 | 39 | 2 | 2.2 |
| 33 | 3 | 2.2 | 40 | 2 | 2.2 |
| 34 | 2 | 1.4 | 41 | 1 | 1.1 |
| 35 | 5 | 3.6 | 42 | 3 | 3.3 |
| 36 | 3 | 2.2 | 43 | 3 | 3.3 |
| 37 | 3 | 2.2 | 45 | 3 | 3.3 |
| 38 | 4 | 2.9 | 46 | 2 | 2.2 |
| 39 | 4 | 2.9 | 47 | 4 | 4.3 |
| 40 | 2 | 1.4 | 48 | 1 | 1.1 |
| 41 | 3 | 2.2 | 50 | 2 | 2.2 |
| 42 | 1 | .7 | 52 | 1 | 1.1 |
| 43 | 2 | 1.4 | 56 | 1 | 1.1 |
| 44 | 2 | 1.4 | 62 | 1 | 1.1 |
| 45 | 2 | 1.4 | 66 | 1 | 1.1 |
| 48 | 1 | .7 | 67 | 1 | 1.1 |
| 49 | 1 | .7 | 93 | 1 | 1.1 |
| 50 | 1 | .7 | Total | 92 | 100.0 |
| 52 | 1 | .7 | | | |
| 53 | 1 | .7 | | | |
| 58 | 1 | .7 | | | |
| 59 | 2 | 1.4 | | | |
| 76 | 1 | .7 | | | |
| Total | 138 | 100.0 | | | |

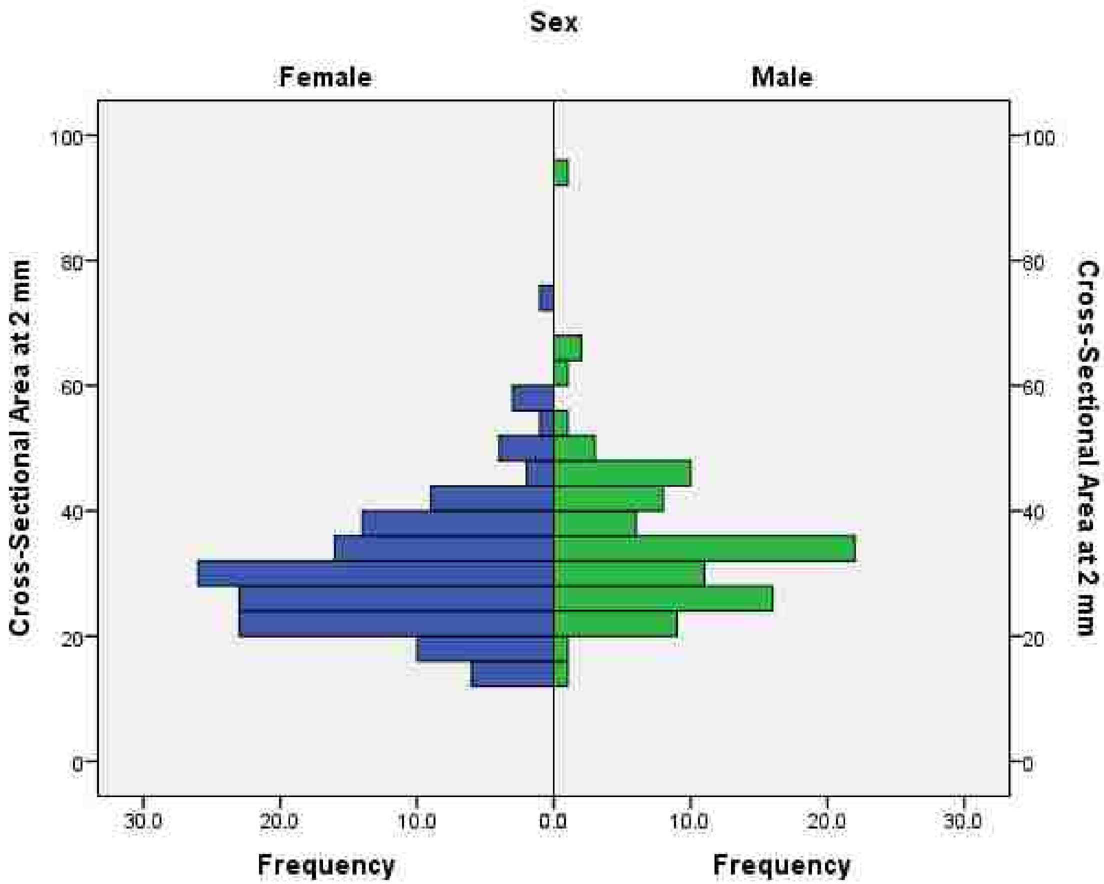



*Figure 4.9.* Histogram illustrating distribution of cross-sectional area at 2 mm in males and females

Table 4.49

*Frequency Table for Cross-Sectional Area at 4 mm in Males vs. Females*

| Females | | | Males | | |
|---|---|---|---|---|---|
| $mm^2$ | Frequency | Valid Percent | $mm^2$ | Frequency | Valid Percent |
| 12 | 1 | .6 | 12 | 1 | .9 |
| 13 | 1 | .6 | 16 | 1 | .9 |
| 14 | 3 | 1.8 | 17 | 2 | 1.8 |
| 15 | 2 | 1.2 | 18 | 1 | .9 |
| 16 | 4 | 2.4 | 19 | 2 | 1.8 |
| 17 | 4 | 2.4 | 20 | 2 | 1.8 |
| 18 | 6 | 3.7 | 21 | 7 | 6.4 |
| 19 | 3 | 1.8 | 22 | 5 | 4.6 |
| 20 | 8 | 4.9 | 23 | 4 | 3.7 |
| 21 | 10 | 6.1 | 24 | 2 | 1.8 |
| 22 | 13 | 7.9 | 25 | 3 | 2.8 |
| 23 | 4 | 2.4 | 26 | 5 | 4.6 |
| 24 | 8 | 4.9 | 27 | 8 | 7.3 |
| 25 | 11 | 6.7 | 28 | 9 | 8.3 |
| 26 | 9 | 5.5 | 29 | 6 | 5.5 |
| 27 | 11 | 6.7 | 30 | 2 | 1.8 |
| 28 | 5 | 3.0 | 31 | 9 | 8.3 |
| 29 | 5 | 3.0 | 32 | 2 | 1.8 |
| 30 | 5 | 3.0 | 33 | 2 | 1.8 |
| 31 | 6 | 3.7 | 34 | 2 | 1.8 |
| 32 | 7 | 4.3 | 35 | 1 | .9 |
| 33 | 4 | 2.4 | 36 | 3 | 2.8 |
| 34 | 3 | 1.8 | 37 | 4 | 3.7 |
| 35 | 4 | 2.4 | 38 | 4 | 3.7 |
| 36 | 1 | .6 | 39 | 3 | 2.8 |
| 37 | 10 | 6.1 | 40 | 2 | 1.8 |
| 38 | 2 | 1.2 | 42 | 2 | 1.8 |
| 40 | 2 | 1.2 | 43 | 1 | .9 |
| 43 | 1 | .6 | 44 | 1 | .9 |
| 44 | 3 | 1.8 | 45 | 1 | .9 |
| 45 | 1 | .6 | 46 | 3 | 2.8 |
| 47 | 1 | .6 | 47 | 1 | .9 |
| 48 | 1 | .6 | 48 | 2 | 1.8 |
| 50 | 1 | .6 | 50 | 1 | .9 |
| 56 | 1 | .6 | 53 | 1 | .9 |
| 57 | 1 | .6 | 57 | 1 | .9 |
| 59 | 1 | .6 | 70 | 1 | .9 |
| 76 | 1 | .6 | 73 | 1 | .9 |
| Total | 164 | 100.0 | 84 | 1 | .9 |
| | | | Total | 109 | 100.0 |

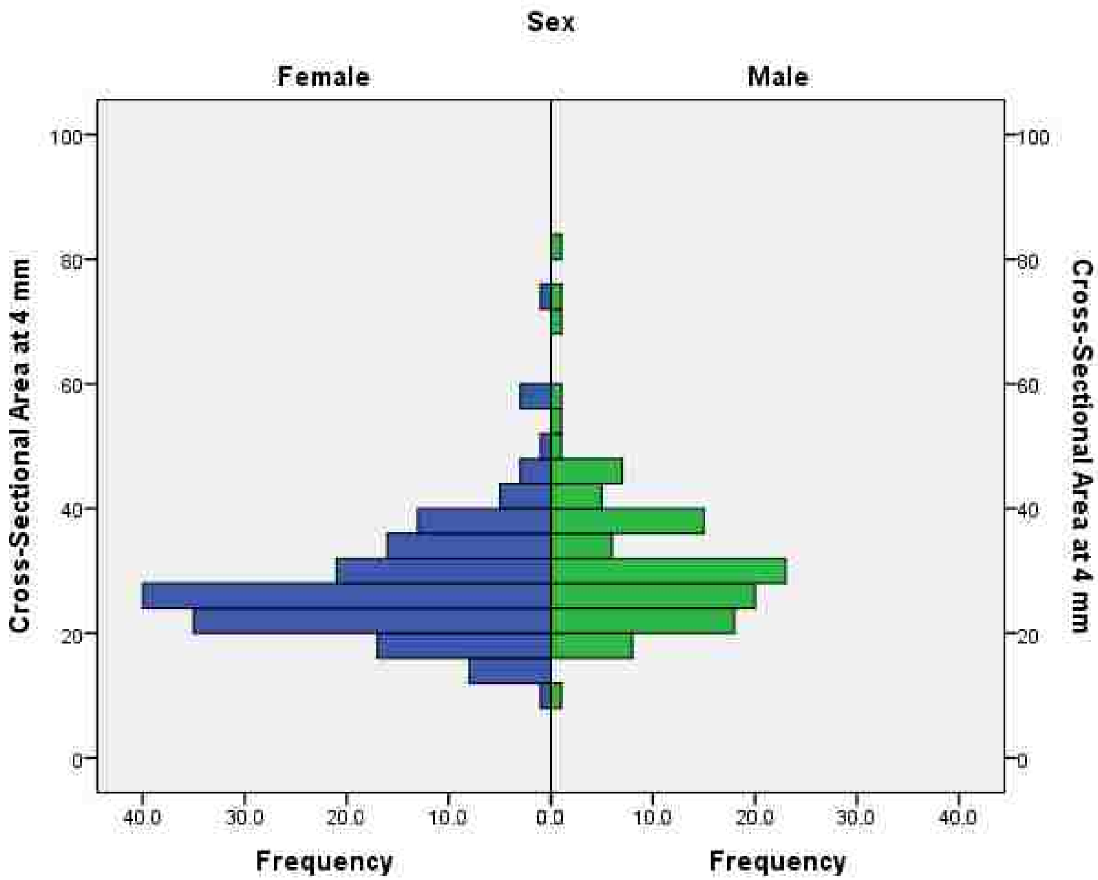



*Figure 4.10.* Histogram illustrating distribution of cross-sectional area at 4 mm in males and females

Table 4.50

*Frequency Table for Cross-Sectional Area at 6 mm in Males vs. Females*

| Females | | | Males | | |
|---|---|---|---|---|---|
| $mm^2$ | Frequency | Valid Percent | $mm^2$ | Frequency | Valid Percent |
| 12 | 1 | .7 | 15 | 1 | 1.0 |
| 14 | 2 | 1.3 | 18 | 1 | 1.0 |
| 15 | 4 | 2.7 | 19 | 1 | 1.0 |
| 16 | 8 | 5.4 | 20 | 2 | 2.0 |
| 17 | 7 | 4.7 | 21 | 5 | 5.1 |
| 18 | 9 | 6.0 | 22 | 4 | 4.0 |
| 19 | 3 | 2.0 | 23 | 6 | 6.1 |
| 20 | 9 | 6.0 | 24 | 7 | 7.1 |
| 21 | 7 | 4.7 | 25 | 5 | 5.1 |
| 22 | 5 | 3.4 | 26 | 7 | 7.1 |
| 23 | 8 | 5.4 | 27 | 5 | 5.1 |
| 24 | 6 | 4.0 | 28 | 3 | 3.0 |
| 25 | 7 | 4.7 | 29 | 5 | 5.1 |
| 26 | 7 | 4.7 | 30 | 4 | 4.0 |
| 27 | 4 | 2.7 | 31 | 2 | 2.0 |
| 28 | 6 | 4.0 | 32 | 4 | 4.0 |
| 29 | 9 | 6.0 | 33 | 2 | 2.0 |
| 30 | 4 | 2.7 | 34 | 3 | 3.0 |
| 31 | 5 | 3.4 | 35 | 4 | 4.0 |
| 32 | 3 | 2.0 | 36 | 4 | 4.0 |
| 33 | 9 | 6.0 | 37 | 5 | 5.1 |
| 34 | 5 | 3.4 | 38 | 3 | 3.0 |
| 35 | 2 | 1.3 | 39 | 2 | 2.0 |
| 36 | 3 | 2.0 | 40 | 3 | 3.0 |
| 37 | 2 | 1.3 | 41 | 2 | 2.0 |
| 39 | 4 | 2.7 | 42 | 2 | 2.0 |
| 41 | 2 | 1.3 | 44 | 1 | 1.0 |
| 42 | 1 | .7 | 45 | 1 | 1.0 |
| 43 | 1 | .7 | 47 | 1 | 1.0 |
| 46 | 1 | .7 | 49 | 1 | 1.0 |
| 47 | 1 | .7 | 50 | 1 | 1.0 |
| 50 | 1 | .7 | 56 | 1 | 1.0 |
| 52 | 1 | .7 | 63 | 1 | 1.0 |
| 56 | 1 | .7 | Total | 99 | 100.0 |
| 64 | 1 | .7 | | | |
| Total | 149 | 100.0 | | | |

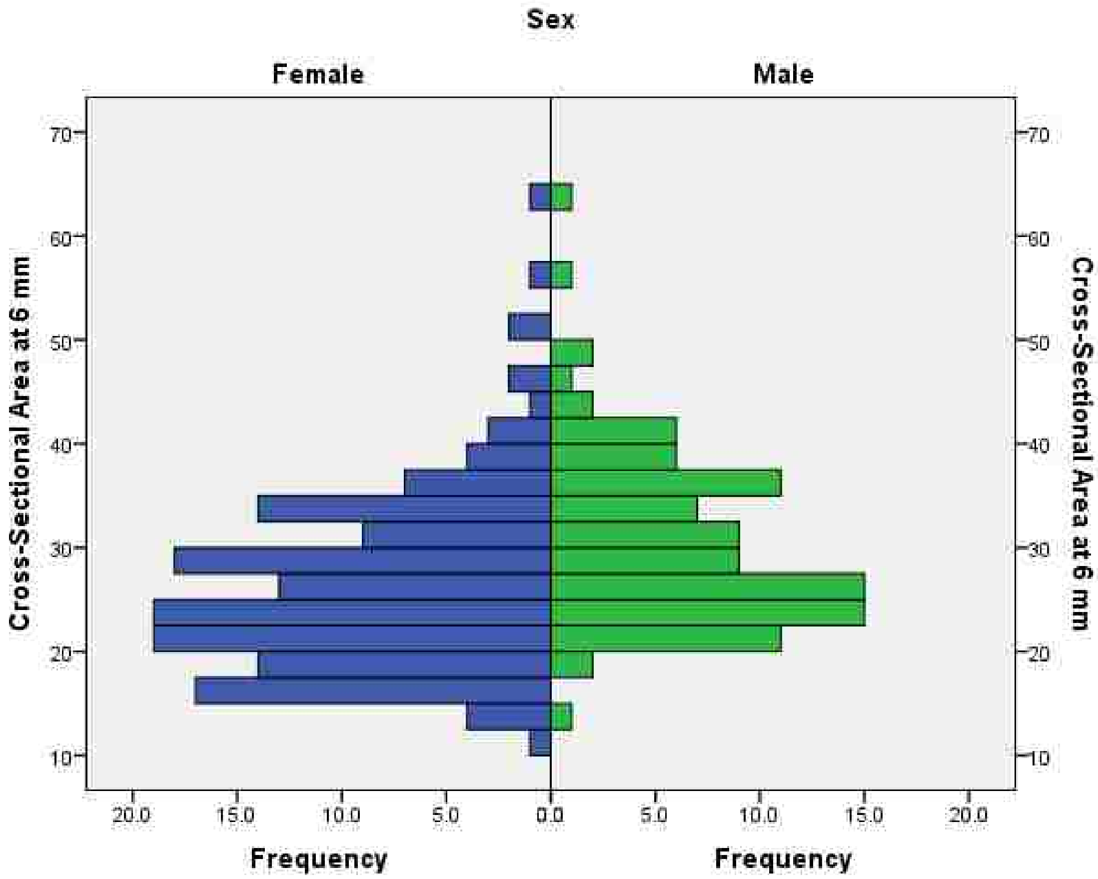



*Figure 4.11*. Histogram illustrating distribution of cross-sectional area at 6 mm in males and females

Table 4.51

*Frequency Table for Cross-Sectional Area at 8 mm in Males vs. Females*

| Females | | | Males | | |
|---|---|---|---|---|---|
| $mm^2$ | Frequency | Valid Percent | $mm^2$ | Frequency | Valid Percent |
| 15 | 4 | 4.5 | 6 | 1 | 1.7 |
| 16 | 4 | 4.5 | 12 | 1 | 1.7 |
| 17 | 7 | 8.0 | 15 | 1 | 1.7 |
| 18 | 4 | 4.5 | 16 | 1 | 1.7 |
| 19 | 1 | 1.1 | 18 | 1 | 1.7 |
| 20 | 8 | 9.1 | 19 | 1 | 1.7 |
| 21 | 9 | 10.2 | 20 | 3 | 5.2 |
| 22 | 4 | 4.5 | 21 | 1 | 1.7 |
| 23 | 8 | 9.1 | 22 | 3 | 5.2 |
| 24 | 9 | 10.2 | 23 | 2 | 3.4 |
| 25 | 2 | 2.3 | 24 | 2 | 3.4 |
| 26 | 1 | 1.1 | 25 | 1 | 1.7 |
| 27 | 4 | 4.5 | 26 | 2 | 3.4 |
| 28 | 1 | 1.1 | 27 | 5 | 8.6 |
| 29 | 3 | 3.4 | 29 | 3 | 5.2 |
| 30 | 1 | 1.1 | 30 | 6 | 10.3 |
| 31 | 4 | 4.5 | 31 | 1 | 1.7 |
| 32 | 2 | 2.3 | 32 | 2 | 3.4 |
| 33 | 4 | 4.5 | 33 | 2 | 3.4 |
| 34 | 2 | 2.3 | 34 | 4 | 6.9 |
| 36 | 1 | 1.1 | 35 | 1 | 1.7 |
| 37 | 1 | 1.1 | 36 | 2 | 3.4 |
| 39 | 2 | 2.3 | 37 | 4 | 6.9 |
| 43 | 1 | 1.1 | 38 | 3 | 5.2 |
| 44 | 1 | 1.1 | 41 | 1 | 1.7 |
| Total | 88 | 100.0 | 42 | 1 | 1.7 |
| | | | 43 | 1 | 1.7 |
| | | | 45 | 1 | 1.7 |
| | | | 52 | 1 | 1.7 |
| | | | Total | 58 | 100.0 |

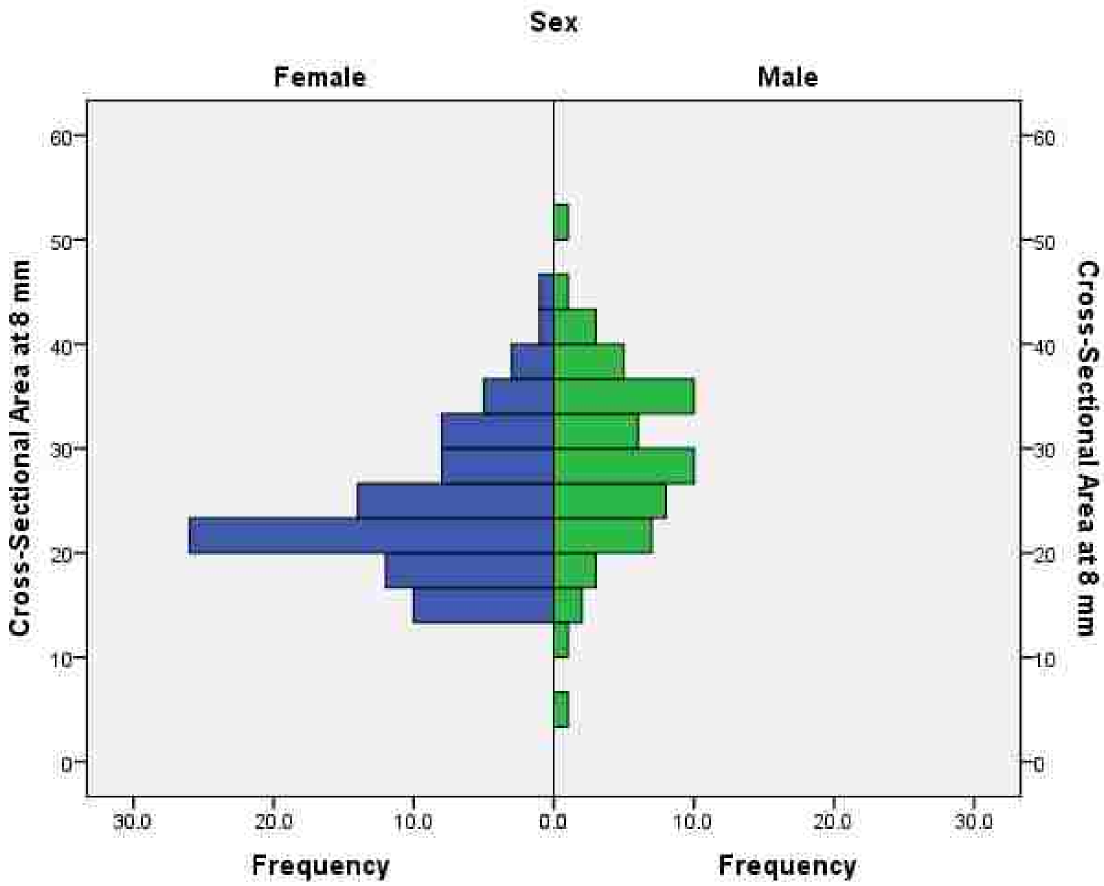



*Figure 4.12.* Histogram illustrating distribution of cross-sectional area at 8 mm in males and females

Independent samples t tests were used to determine if there was a significant difference in cross-sectional area measurements between males and females within each age group. In age group 1, there was no statistically significant difference between males and females for the cross-sectional area at 2 mm ($p$ = .119), 4 mm ($p$ = .190), 6 mm ($p$ = .255), and 8 mm ($p$ = .869) lateral to the internal auditory meatus (Table 4.52). In age group 2, there was a statistically significant difference between males and females for the cross-sectional area at 2 mm ($p$ = .044), 4 mm ($p$ = .048), 6 mm ($p$ = .007), and 8 mm ($p$ = .003) lateral to the internal auditory meatus (Table 4.53). In age group 3, there was no statistically significant difference between males and females for the cross-sectional area at 6 mm (*p* = .255) and 8 mm (*p* = .131) while there was a statistically significant difference at 2 mm (*p* = .025) and 4 mm (*p* = .046) lateral to the internal auditory meatus (Table 4.54). In age group 4, there was no statistically significant difference between males and females for the cross-sectional area at 2 mm (*p* = .123) and 4 mm (*p* = .065) while there was a statistically significant difference at 6 mm (*p* = .013), and 8 mm (*p* = .043) lateral to the internal auditory meatus (Table 4.55). In age group 5, there was no statistically significant difference between males and females for the cross-sectional area at 2 mm (*p* = .638), 4 mm (*p* = .662), 6 mm (*p* = .068), and 8 mm (*p* = .455) lateral to the internal auditory meatus (Table 4.56).

Table 4.52

*Comparing the Cross-Sectional Area in Males vs. Females in Age Group 1 (Age 6-10)*

*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 Difference | Std. Error Difference | Lower | Upper |
| Area 2 | Equal variances assumed | 1.133 | .294 | -1.596 | 39 | .119 | -8.84490 | 5.54245 | -20.05555 | 2.36576 |
| | Equal variances not assumed | | | -1.224 | 9.783 | .249 | -8.84490 | 7.22373 | -24.98899 | 7.29920 |
| Area 4 | Equal variances assumed | 1.952 | .169 | -1.330 | 48 | .190 | -5.91706 | 4.44777 | -14.85990 | 3.02577 |
| | Equal variances not assumed | | | -1.075 | 14.145 | .301 | -5.91706 | 5.50612 | -17.71516 | 5.88104 |
| Area 6 | Equal variances assumed | .927 | .342 | -1.155 | 39 | .255 | -4.61830 | 3.99984 | -12.70874 | 3.47214 |
| | Equal variances not assumed | | | -.931 | 10.176 | .373 | -4.61830 | 4.96129 | -15.64686 | 6.41026 |
| Area 8 | Equal variances assumed | .202 | .658 | -.167 | 20 | .869 | -.54688 | 3.27021 | -7.36842 | 6.27467 |
| | Equal variances not assumed | | | -.158 | 8.163 | .878 | -.54688 | 3.45904 | -8.49572 | 7.40197 |

Table 4.53

*Comparing the Cross-Sectional Area in Males vs. Females in Age Group 2 (Age 11-13)*

*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 Difference | Std. Error Difference | Lower | Upper |
| Area 2 | Equal variances assumed | 3.792 | .055 | -2.042 | 85 | .044 | -4.15315 | 2.03387 | -8.19703 | -.10927 |
| | Equal variances not assumed | | | -1.983 | 67.500 | .051 | -4.15315 | 2.09386 | -8.33194 | .02564 |
| Area 4 | Equal variances assumed | 4.033 | .047 | -2.082 | 106 | .040 | -4.01397 | 1.92759 | -7.83560 | -.19234 |
| | Equal variances not assumed | | | -2.009 | 81.024 | .048 | -4.01397 | 1.99771 | -7.98877 | -.03917 |
| Area 6 | Equal variances assumed | 1.199 | .276 | -2.771 | 95 | .007 | -4.55572 | 1.64395 | -7.81937 | -1.29207 |
| | Equal variances not assumed | | | -2.719 | 82.249 | .008 | -4.55572 | 1.67575 | -7.88916 | -1.22228 |
| Area 8 | Equal variances assumed | 6.417 | .014 | -3.386 | 55 | .001 | -6.54004 | 1.93154 | -10.41093 | -2.66915 |
| | Equal variances not assumed | | | -3.151 | 35.639 | .003 | -6.54004 | 2.07530 | -10.75042 | -2.32966 |

Table 4.54

*Comparing the Cross-Sectional Area in Males vs. Females in Age Group 3 (Age 14-16)*

*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 Difference | Std. Error Difference | Lower | Upper |
| Area 2 | Equal variances assumed | .011 | .917 | -2.298 | 64 | .025 | -6.16724 | 2.68422 | -11.52958 | -.80490 |
| | Equal variances not assumed | | | -2.300 | 63.932 | .025 | -6.16724 | 2.68183 | -11.52493 | -.80956 |
| Area 4 | Equal variances assumed | .005 | .946 | -2.026 | 76 | .046 | -4.26706 | 2.10580 | -8.46112 | -.07301 |
| | Equal variances not assumed | | | -2.031 | 74.854 | .046 | -4.26706 | 2.10045 | -8.45151 | -.08262 |
| Area 6 | Equal variances assumed | 2.142 | .148 | -1.146 | 73 | .255 | -2.43889 | 2.12793 | -6.67984 | 1.80206 |
| | Equal variances not assumed | | | -1.175 | 69.052 | .244 | -2.43889 | 2.07592 | -6.58017 | 1.70239 |
| Area 8 | Equal variances assumed | .209 | .650 | -1.539 | 43 | .131 | -3.89000 | 2.52737 | -8.98692 | 1.20692 |
| | Equal variances not assumed | | | -1.511 | 37.368 | .139 | -3.89000 | 2.57469 | -9.10508 | 1.32508 |

Table 4.55

*Comparing the Cross-Sectional Area in Males vs. Females in Age Group 4 (Age 17-19)*

*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 Difference | Std. Error Difference | Lower | Upper |
| Area 2 | Equal variances assumed | .035 | .853 | -1.614 | 19 | .123 | -5.52733 | 3.42505 | -12.69605 | 1.64138 |
| | Equal variances not assumed | | | -1.553 | 8.590 | .157 | -5.52733 | 3.55986 | -13.63923 | 2.58456 |
| Area 4 | Equal variances assumed | 1.225 | .282 | -1.953 | 20 | .065 | -6.18838 | 3.16823 | -12.79720 | .42044 |
| | Equal variances not assumed | | | -1.831 | 10.167 | .097 | -6.18838 | 3.37960 | -13.70187 | 1.32510 |
| Area 6 | Equal variances assumed | 1.224 | .282 | -2.715 | 20 | .013 | -8.70790 | 3.20684 | -15.39726 | -2.0186 |
| | Equal variances not assumed | | | -2.456 | 9.433 | .035 | -8.70790 | 3.54489 | -16.67122 | -.74459 |
| Area 8 | Equal variances assumed | .113 | .742 | -2.207 | 15 | .043 | -6.43394 | 2.91542 | -12.64802 | -.21986 |
| | Equal variances not assumed | | | -2.148 | 9.628 | .058 | -6.43394 | 2.99553 | -13.14356 | .27568 |

Table 4.56

*Comparing the Cross-Sectional Area in Males vs. Females in Age Group 5 (Age 20-24)*

*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 Difference | Std. Error Difference | Lower | Upper |
| Area 2 | Equal variances assumed | 2.289 | .154 | -.482 | 13 | .638 | -2.56400 | 5.31878 | -14.05452 | 8.92652 |
| | Equal variances not assumed | | | -.630 | 12.631 | .540 | -2.56400 | 4.07058 | -11.38413 | 6.25613 |
| Area 4 | Equal variances assumed | 1.676 | .218 | -.448 | 13 | .662 | -1.67000 | 3.72978 | -9.72771 | 6.38771 |
| | Equal variances not assumed | | | -.558 | 12.981 | .587 | -1.67000 | 2.99417 | -8.13945 | 4.79945 |
| Area 6 | Equal variances assumed | .886 | .367 | -2.027 | 11 | .068 | -6.10325 | 3.01039 | -12.72906 | .52256 |
| | Equal variances not assumed | | | -2.117 | 9.823 | .061 | -6.10325 | 2.88250 | -12.54155 | .33505 |
| Area 8 | Equal variances assumed | 8.526 | .062 | -.855 | 3 | .455 | -5.18833 | 6.06548 | -24.49141 | 14.1148 |
| | Equal variances not assumed | | | -1.104 | 2.003 | .384 | -5.18833 | 4.69941 | -25.38090 | 15.0042 |

A Pearson's correlation analysis was conducted to determine if there was a relationship between age and the cross-sectional area of the internal auditory canal. When both sexes were combined, there was a negative correlation between age and the cross-sectional area at 2 mm ($p$ = .013), 4 mm ($p$ = .001), and 6 mm ($p$ = .016) while there was no relationship at 8 mm ($p$ = .843) (Table 4.57 and Figure 4.13, Figure 4.14, and Figure 4.15).

When controlling for sex, there was a negative correlation between age and the cross-sectional area at 2 mm ($p$ = .020), 4 mm ($p$ = .003), and 6 mm ($p$ = .015) lateral to the internal auditory meatus in females (Table 4.58 and Figure 4.16, Figure 4.17, and Figure 4.18.)  In males, there was only a negative correlation (Table 4.58 and Figure 4.19) between age and the cross-sectional area at 4 mm ($p$ = .048).

Table 4.57

*Correlations between the Cross-Sectional Area at 2 mm, 4 mm, 6 mm, 8 mm, and Age in Males and Females*

| | | Age | Area 2 | Area 4 | Area 6 | Area 8 |
|---|---|---|---|---|---|---|
| Age | Pearson Correlation | 1 | -.163* | -.196** | -.152* | -.017 |
| | Sig. (2-tailed) | | .013 | .001 | .016 | .843 |
| | N | 276 | 230 | 273 | 248 | 146 |
| Area 2 | Pearson Correlation | -.163* | 1 | .838** | .729** | .413** |
| | Sig. (2-tailed) | .013 | | .000 | .000 | .000 |
| | N | 230 | 230 | 230 | 203 | 107 |
| Area 4 | Pearson Correlation | -.196** | .838** | 1 | .843** | .555** |
| | Sig. (2-tailed) | .001 | .000 | | .000 | .000 |
| | N | 273 | 230 | 273 | 245 | 144 |
| Area 6 | Pearson Correlation | -.152* | .729** | .843** | 1 | .727** |
| | Sig. (2-tailed) | .016 | .000 | .000 | | .000 |
| | N | 248 | 203 | 245 | 248 | 141 |
| Area 8 | Pearson Correlation | -.017 | .413** | .555** | .727** | 1 |
| | Sig. (2-tailed) | .843 | .000 | .000 | .000 | |
| | N | 146 | 107 | 144 | 141 | 146 |

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

**. Correlation is significant at the 0.01 level (2-tailed).

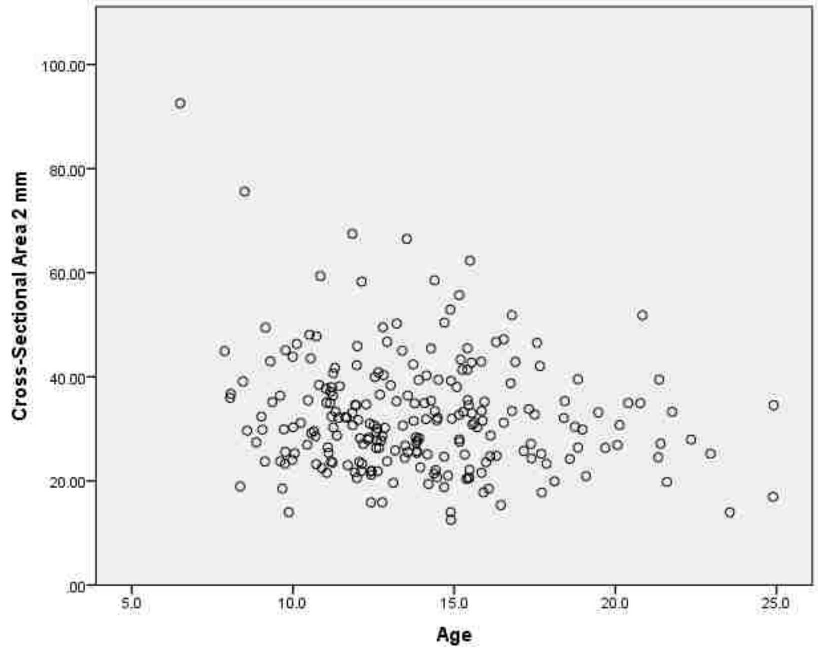



*Figure 4.13.* Scatterplot of the correlation between the cross-sectional area at 2 mm and age in males and females

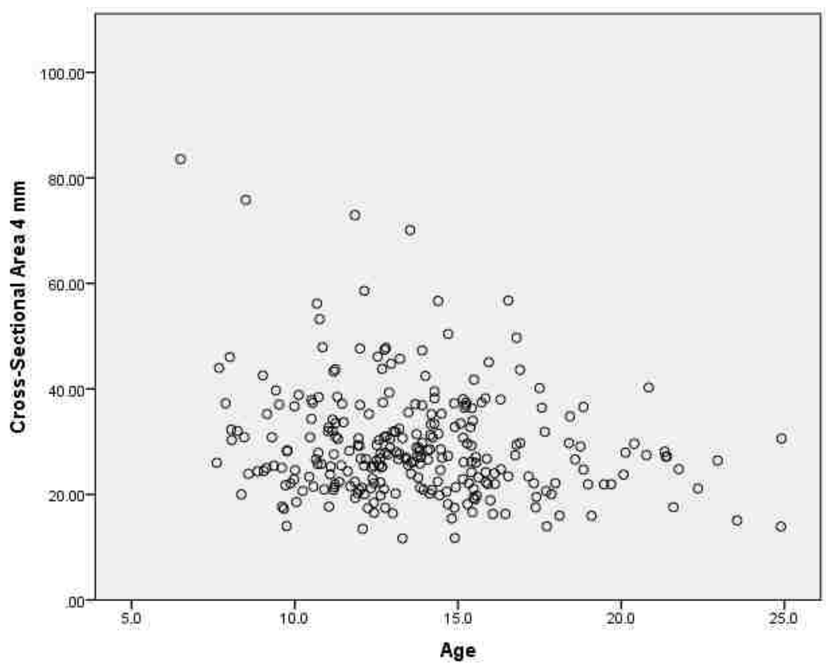



*Figure 4.14.* Scatterplot of the correlation between the cross-sectional area at 4mm and age in males and females

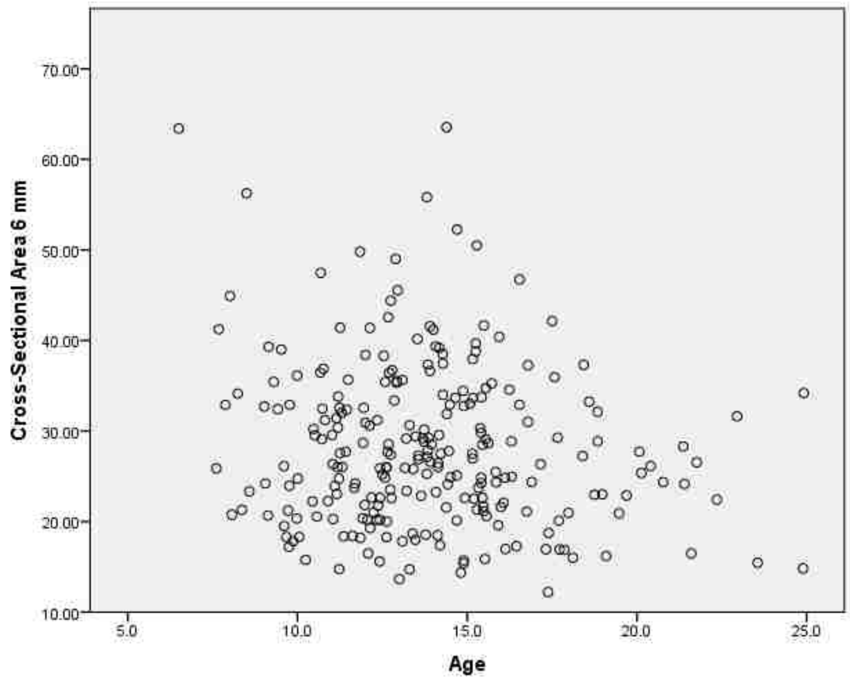



*Figure 4.15.* Scatterplot of the correlation between the cross-sectional area at 6 mm and age in males and females

Table 4.58

Correlations between the Cross-Sectional Area and Age in Males vs. Females

| Gender | | | Age | Area 2 | Area 4 | Area 6 | Area 8 |
|---|---|---|---|---|---|---|---|
| Female | Age | Pearson | 1 | -.198* | -.229** | -.199* | -.074 |
| | | Sig. (2-tailed) | | .020 | .003 | .015 | .496 |
| | | N | 165 | 138 | 164 | 149 | 88 |
| | Area 2 | Pearson | -.198* | 1 | .817** | .722** | .327** |
| | | Sig. (2-tailed) | .020 | | .000 | .000 | .008 |
| | | N | 138 | 138 | 138 | 123 | 65 |
| | Area 4 | Pearson | -.229** | .817** | 1 | .862** | .620** |
| | | Sig. (2-tailed) | .003 | .000 | | .000 | .000 |
| | | N | 164 | 138 | 164 | 148 | 88 |
| | Area 6 | Pearson | -.199* | .722** | .862** | 1 | .774** |
| | | Sig. (2-tailed) | .015 | .000 | .000 | | .000 |
| | | N | 149 | 123 | 148 | 149 | 86 |
| | Area 8 | Pearson | -.074 | .327** | .620** | .774** | 1 |
| | | Sig. (2-tailed) | .496 | .008 | .000 | .000 | |
| | | N | 88 | 65 | 88 | 86 | 88 |
| Male | Age | Pearson | 1 | -.159 | -.190* | -.137 | .021 |
| | | Sig. (2-tailed) | | .129 | .048 | .176 | .874 |
| | | N | 111 | 92 | 109 | 99 | 58 |
| | Area 2 | Pearson | -.159 | 1 | .845** | .715** | .387* |
| | | Sig. (2-tailed) | .129 | | .000 | .000 | .011 |
| | | N | 92 | 92 | 92 | 80 | 42 |
| | Area 4 | Pearson | -.190* | .845** | 1 | .822** | .440** |
| | | Sig. (2-tailed) | .048 | .000 | | .000 | .001 |
| | | N | 109 | 92 | 109 | 97 | 56 |
| | Area 6 | Pearson | -.137 | .715** | .822** | 1 | .609** |
| | | Sig. (2-tailed) | .176 | .000 | .000 | | .000 |
| | | N | 99 | 80 | 97 | 99 | 55 |
| | Area 8 | Pearson | .021 | .387* | .440** | .609** | 1 |
| | | Sig. (2-tailed) | .874 | .011 | .001 | .000 | |
| | | N | 58 | 42 | 56 | 55 | 58 |

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

**. Correlation is significant at the 0.01 level (2-tailed).

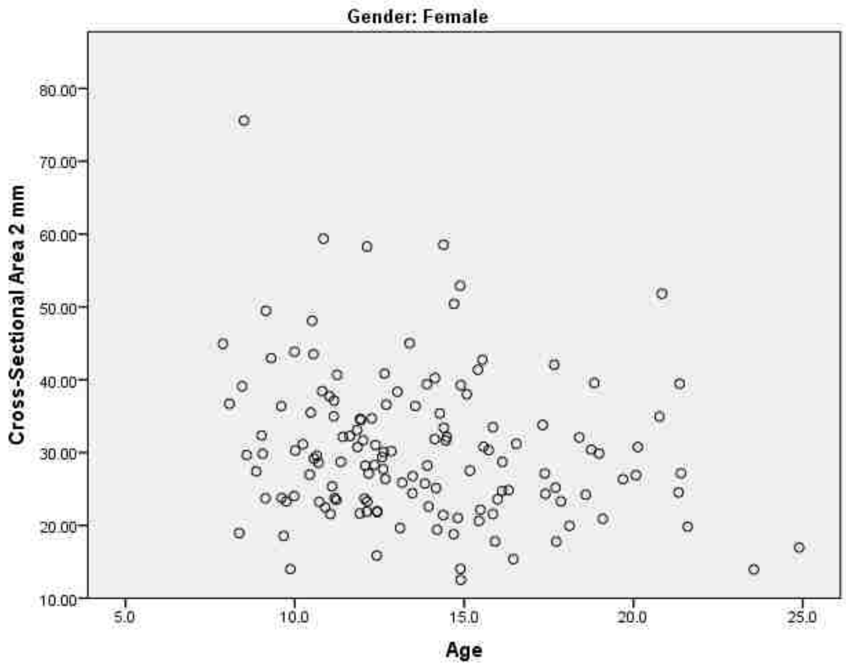



*Figure 4.16.* Scatterplot of the correlation between the cross-sectional area at 2 mm and age in females

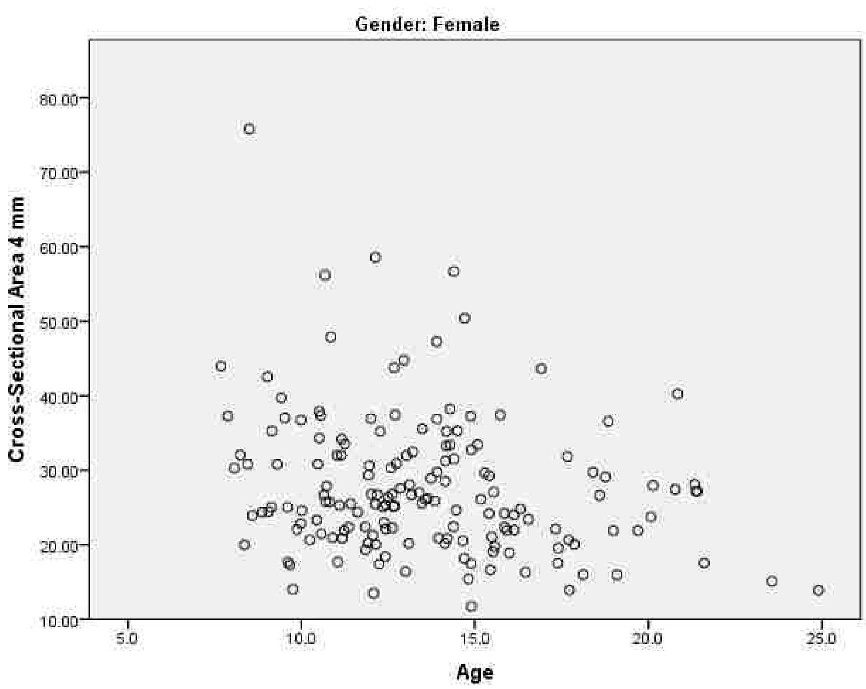



*Figure 4.17.* Scatterplot of the correlation between the cross-sectional area at 4 mm and age in females

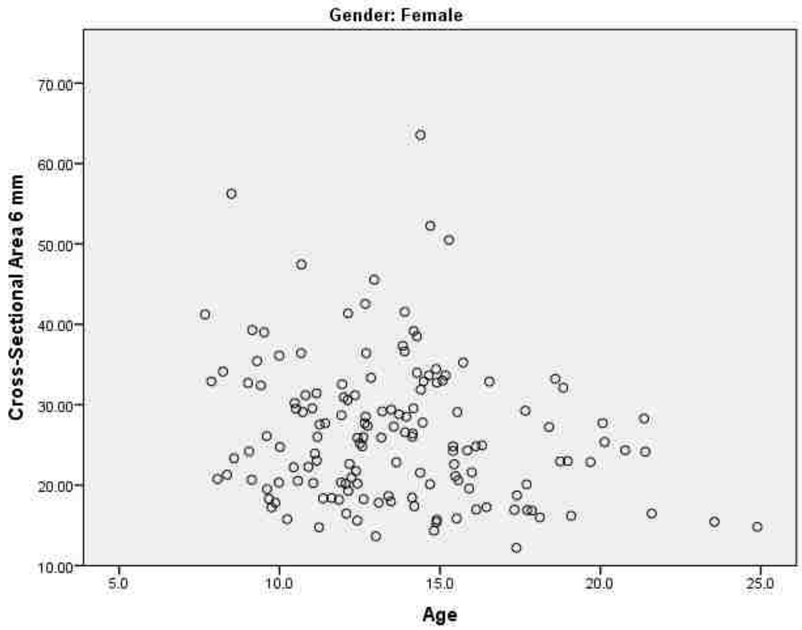



*Figure 4.18.* Scatterplot of the correlation between the cross-sectional area at 6 mm and age in females

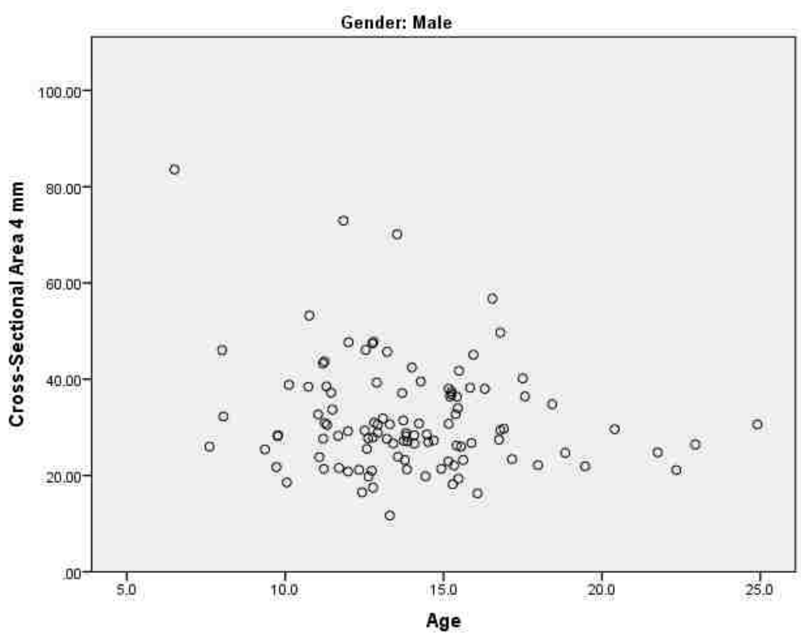



*Figure 4.19.* Scatterplot of the correlation between the cross-sectional area at 4 mm and age in males

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

Since only the diameter and area methods demonstrated any statistically significant differences between males and females, the anterior and posterior lateral angles were excluded from a logistic regression analysis. Similarly, group 1 was also excluded due to a lack of any significant findings for sexual differences using any of the three methods discussed in this study. A binary logistic regression was performed for groups 2 through 4 to ascertain the effects of the diameters and cross-sectional areas at 2 mm, 4 mm, 6 mm, and 8 mm lateral to the internal auditory meatus on correct sex allocation. The small sample size in group 5 did not allow for a logistic function model to be formed.

### Group 2

The logistic regression model was statistically significant, $X^2 = 19.425$, $p = .013$. The model explained 59.2% (Nagelkerke $R^2$) of the variance in sex and correctly classified 85.3% of all cases, with a predictive value of 90.5% for females and 76.9% for males. Of the eight predictor variables, only one was statistically significant: the cross-sectional area at 8 mm, $p = .012$ (Table 4.59).

### Group 3

The logistic regression model was statistically significant, $X^2 = 18.185$, $p = .020$. The model explained 56.2% (Nagelkerke $R^2$) of the variance in sex and correctly classified 84.8% of all cases, with a predictive value of 82.4% for females and 87.5% for males. Of the eight predictor variables, two were statistically significant: the diameter at 6 mm, $p = .020$, and the cross-sectional area at 6 mm, $p = .039$ (as shown in Table 4.60).

**Group 4**

A logistic function model was unable to be created using all eight predictor variables for diameter and area. However, a valid model was created by eliminating the variables that were not found to exhibit sexual dimorphism in the diameter and area methods. Thus, only the diameters at 4 mm and 6 mm and the cross-sectional areas at 6 mm and 8 mm were used to create a model. The logistic regression model was statistically significant, $X^2 = 9.848$, $p = .043$. The model explained 60.5% (Nagelkerke $R^2$) of the variance in sex and correctly classified 88.2% of all cases, with a predictive value of 90.9% for females and 83.3% for males. Of the four predictor variables, none were statistically significant in the final equation (as shown in Table 4.61). The problems encountered in forming the logistic function model for group 4 were most likely due to the small sample size. A larger sample size would likely improve the logistic function model and allow for all eight diameter and area variables to be used.

Table 4.59

*Logistic Regression Analysis for Group 2*

*Case Processing Summary*

| *Unweighted Cases*[a] | | *N* | *Percent* |
|---|---|---|---|
| *Selected Cases* | *Included in Analysis* | 34 | 31.2 |
| | *Missing Cases* | 75 | 68.8 |
| | *Total* | 109 | 100.0 |
| *Unselected Cases* | | 0 | .0 |
| *Total* | | 109 | 100.0 |

*a. If weight is in effect, see classification table for the total number of cases.*

*Classification Table*[a]

| | | | *Predicted* | | |
|---|---|---|---|---|---|
| | | | *Gender* | | *Percentage* |
| | *Observed* | | *Female* | *Male* | *Correct* |
| *Step 1* | *Gender* | *Female* | 19 | 2 | 90.5 |
| | | *Male* | 3 | 10 | 76.9 |
| | *Overall Percentage* | | | | 85.3 |

*a. The cut value is .500*

*Variables in the Equation*

| | | *B* | *S.E.* | *Wald* | *df* | *Sig.* | *Exp(B)* | *95% C.I.for EXP(B)* *Lower* | *Upper* |
|---|---|---|---|---|---|---|---|---|---|
| *Step 1*[a] | *Diam 2* | .423 | .769 | .303 | 1 | .582 | 1.527 | .338 | 6.898 |
| | *Diam 4* | .056 | 1.529 | .001 | 1 | .971 | 1.057 | .053 | 21.184 |
| | *Diam 6* | -1.259 | 1.748 | .519 | 1 | .471 | .284 | .009 | 8.724 |
| | *Diam 8* | .563 | .348 | 2.617 | 1 | .106 | 1.756 | .888 | 3.472 |
| | *Area 2* | -.036 | .169 | .046 | 1 | .831 | .965 | .693 | 1.343 |
| | *Area 4* | .084 | .300 | .079 | 1 | .778 | 1.088 | .604 | 1.959 |
| | *Area 6* | -.116 | .209 | .308 | 1 | .579 | .890 | .591 | 1.341 |
| | *Area 8* | .354 | .140 | 6.361 | 1 | .012 | 1.425 | 1.082 | 1.877 |
| | *Constant* | -7.199 | 5.417 | 1.766 | 1 | .184 | .001 | | |

*a. Variable(s) entered on step 1: Diam2, Diam4, Diam6, Diam8, Area2, Area4, Area6, Area8.*

Table 4.60

*Logistic Regression Analysis for Group 3*

*Case Processing Summary*

| *Unweighted Cases*[a] | | *N* | *Percent* |
|---|---|---|---|
| *Selected Cases* | *Included in Analysis* | 33 | 41.8 |
| | *Missing Cases* | 46 | 58.2 |
| | *Total* | 79 | 100.0 |
| *Unselected Cases* | | 0 | .0 |
| *Total* | | 79 | 100.0 |

*a. If weight is in effect, see classification table for the total number of cases.*

*Classification Table*[a]

| | | | *Predicted* | | |
|---|---|---|---|---|---|
| | | | *Gender* | | *Percentage* |
| | *Observed* | | *Female* | *Male* | *Correct* |
| *Step 1* | *Gender* | *Female* | 14 | 3 | 82.4 |
| | | *Male* | 2 | 14 | 87.5 |
| | *Overall Percentage* | | | | 84.8 |

*a. The cut value is .500*

*Variables in the Equation*

| | | | | | | | | *95% C.I.for EXP(B)* | |
|---|---|---|---|---|---|---|---|---|---|
| | | *B* | *S.E.* | *Wald* | *df* | *Sig.* | *Exp(B)* | *Lower* | *Upper* |
| *Step 1*[a] | *Diam2* | -1.228 | 1.104 | 1.237 | 1 | .266 | .293 | .034 | 2.550 |
| | *Diam4* | .011 | 1.289 | .000 | 1 | .993 | 1.011 | .081 | 12.654 |
| | *Diam6* | 3.974 | 1.713 | 5.383 | 1 | .020 | 53.201 | 1.853 | 1527.222 |
| | *Diam8* | 1.695 | 1.714 | .978 | 1 | .323 | 5.445 | .189 | 156.521 |
| | *Area2* | .228 | .171 | 1.781 | 1 | .182 | 1.256 | .898 | 1.757 |
| | *Area4* | .119 | .187 | .404 | 1 | .525 | 1.126 | .781 | 1.624 |
| | *Area6* | -.680 | .330 | 4.264 | 1 | .039 | .506 | .265 | .966 |
| | *Area8* | -.025 | .175 | .021 | 1 | .886 | .975 | .692 | 1.374 |
| | *Constant* | -16.733 | 9.329 | 3.217 | 1 | .073 | .000 | | |

*a. Variable(s) entered on step 1: Diam2, Diam4, Diam6, Diam8, Area2, Area4, Area6, Area8.*

Table 4.61

*Logistic Regression Analysis for Group 4 Using Diameter at 4 mm, 6 mm, and Cross-Sectional Area at 6 mm and 8 mm*

*Case Processing Summary*

| *Unweighted Cases*[a] | | *N* | *Percent* |
|---|---|---|---|
| *Selected Cases* | *Included in Analysis* | 17 | 77.3 |
| | *Missing Cases* | 5 | 22.7 |
| | *Total* | 22 | 100.0 |
| *Unselected Cases* | | 0 | .0 |
| *Total* | | 22 | 100.0 |

*a. If weight is in effect, see classification table for the total number of cases.*

*Classification Table*[a]

| | | | *Predicted* | | |
|---|---|---|---|---|---|
| | | | *Gender* | | |
| | *Observed* | | *Female* | *Male* | *Percentage Correct* |
| *Step 1* | *Gender* | *Female* | 10 | 1 | 90.9 |
| | | *Male* | 1 | 5 | 83.3 |
| | *Overall Percentage* | | | | 88.2 |

*a. The cut value is .500*

*Variables in the Equation*

| | | | | | | | | *95% C.I.for EXP(B)* | |
|---|---|---|---|---|---|---|---|---|---|
| | | *B* | *S.E.* | *Wald* | *df* | *Sig.* | *Exp(B)* | *Lower* | *Upper* |
| *Step 1*[a] | *Diam 4* | 1.120 | .986 | 1.290 | 1 | .256 | 3.065 | .444 | 21.176 |
| | *Diam 6* | -2.553 | 2.553 | 1.000 | 1 | .317 | .078 | .001 | 11.604 |
| | *Area 6* | .437 | .325 | 1.804 | 1 | .179 | 1.548 | .818 | 2.930 |
| | *Area 8* | -.102 | .215 | .225 | 1 | .635 | .903 | .592 | 1.377 |
| | *Constant* | -1.495 | 8.415 | .032 | 1 | .859 | .224 | | |

*a. Variable(s) entered on step 1: Diam 4, Diam 6, Area 6, Area 8.*

# Chapter 5 : Discussion

The primary goal of this research was to use CBCT to validate and refine two previously developed metric methods of sex determination using the internal auditory canal of the petrous portion of the temporal bone in subadults. In addition, a new metric method was assessed to determine if the probability of correct allocation of sex could be improved. Overall, the results were mixed, with the accuracy of correct sex allocation ranging from 40% - 88.2% depending on the age group, methods and variables used.

## Bilateral Differences and Intra-Observer Error

The first step of this analysis was to determine if there were any differences in measurements between the right and left petrous bones. Independent samples t tests indicated that bilateral variation in the measurements of the internal auditory canal were negligible, making the left and right petrous portions interchangeable for each of the three methods.

The next step of this analysis was to assess whether the image-based measurements developed for this study could be reliably reproduced. A couple months after the data collection process, ten randomly selected individuals were selected for re-measurement. 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.

## The Lateral Angle Method

The first objective of this study was to evaluate the lateral angle method for sex determination in subadults. The same 45° sectioning point originally developed by Wahl (1981) and further evaluated by Ahlbrecht (1997), Graw et al. (2004), Noren et al.

(2005), Gonçalves et al. (2011), and Morgan (2013) 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. Interesting to note is that some studies measured the lateral angle using the posterior wall of the internal auditory canal (Masotti et al. 2013; Gonçalves et al. 2011; Todd et al. 2010) while others (Akansel et al. 2008, Noren et al. 2005, Graw et al. 2004, Morgan 2013) used the anterior wall of the internal auditory canal. This may partly explain the lack of consistency in statistical results between studies. Both walls were used to measure the lateral angle in this study and were called the anterior lateral angle and posterior lateral angle accordingly.

When measuring the anterior lateral angle in age groups 1, 2, 3, 4, and 5, correct sex allocation was predicted with accuracies of 52.9%, 54.1%, 62.0%, 72.7%, and 40.0%, respectively. When measuring the posterior lateral angle in age groups 1, 2, 3, 4, and 5, correct sex allocation was predicted with accuracies of 68.6%, 55.9%, 59.5%, 59.0%, and 40%, respectively. Overall, it seems the anterior lateral angle is a better predictor of sex in age groups 3 and 4 while the posterior lateral angle is a better predictor of sex in age groups 1 and 2. Neither anterior nor posterior lateral angle was a good predictor of sex in age group 5, but the sample size in this group was exceedingly small (N=15). However, none of these accuracies for either the anterior or posterior lateral angles fall within Novotný et al.'s (1993) guidelines for reliable sex determination traits (Table 2.1). They also fall short of 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.

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.

While Noren et al. concluded that the lateral angle reliably (83.2%) predicts the sex of skeletal remains, others reported a much lower accuracy (Graw et al. 2004; Gonçalves 2011; Masotti 2013; Akansel 2008; Morgan 2013). The inconsistency of previous results along with the current findings support 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 in various studies, it was initially assumed that this could be accounted for by the population specificity of the 45° sectioning point; however, upon further statistical investigation of the data, no other 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, within each age group, and the considerable overlap of lateral angle CBCT measurements between the sexes (females: 26°-83°; males: 25°-80°). These results are consistent with Morgan (2009) who also revealed a significant overlap in the ranges of measurements that did not allow for the determination of a sectioning point that adequately separated the sexes (females: 39°-65°; males: 32°-60°). Similarly, Akansel et al. (2008) had significant overlap in measurements as well (females: 30°-68°; males: 30°-60°). Therefore, the results from the current data suggest that there may be some degree of sexual dimorphism in the lateral angle, but the composition and distribution of the sample used here was inadequate 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 lack of a statistically significant difference between the male and female mean values within each age group. In age group 1, the mean values for the anterior lateral angle were 46.5 ± 10.3° in females and 41.9 ± 7.5° in males. The mean values for the posterior lateral angle were 52.1 ± 10.0° in females and 48.1 ± 10.3° in males. In age group 2, the mean values for the anterior lateral angle were 46.0 ± 9.8° in females and 45.3 ± 11.9° in males. The mean values for the posterior lateral angle were 53.6 ± 11.0° in females and 50.6 ± 11.1° in males. In age group 3, the mean values for the anterior lateral angle were 49.6 ± 10.1° in females and 45.2 ± 10.8° in males. The mean values for the posterior lateral angle were 54.9 ± 10.7° in females and 50.8 ± 11.4° in males. In age group 4, the mean values for the anterior lateral angle were 47.9 ± 10.7° in females and 43.7 ± 4.7° in males. The mean values for the posterior lateral angle were 55.9 ± 12.3° in females and 56.6 ± 4.8° in males. In age group 5, the mean values for the anterior lateral angle were 45.1 ± 10.7° in females and 43.1 ± 4.7° in males. The mean values for the posterior lateral angle were 48.5 ± 10.0° in females and 47.5 ± 6.2° in males.

Although the mean lateral angle value was greater in females than males in all but one group, the difference did not reach statistical significance. This may have been due to the small number of males used in this study. The small sample sizes within each age group (Group 1: 39 females, 12 males; Group 2: 59 females, 50 males; Group 3: 42 females, 37 males; Group 4: 15 females, 7 males; Group 5: 10 females, 5 males), particularly with reference to the male sub-sample, may have precluded the ability to more accurately interpret the larger populational pattern of sex differences in lateral angle. Morgan et al. (2009) and Akansel et al. (2008) experienced a similar issue when analyzing lateral angle sex differences in a small sub-sample of sub-adult subjects (Morgan: 40 males, 15 females; Akansel: 17 males, 5 females). Despite a large numerical difference between female and male means, the difference was not statistically significant due to the inadequate sample size and small number of female subjects.

Although no statistical significance was found in sex differences between the lateral angle measurements in males and females, 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. However, its use in anthropological applications is limited and not as practical as using other highly dimorphic skeletal elements such as the pelvis and skull. It is recommended that either a larger sample size with equal sex distribution, or the addition of other morphological methods in combination with the lateral angle method, be used in future research using CBCT scan data to analyze the lateral angle in order to determine, with greater confidence, whether the lateral angle is useful for sex determination.

The inconsistency between the statistical results of the current study and those previously published on the lateral angle may also be attributed to differences in methodologies. Prior casting studies (Noren et al. 2005; Gonçalves et al. 2011; Graw et al. 2004; Masotti 2013) indicated some amount of accuracy in sex determination ranging from 60% - 83.2% when measuring the lateral angle. However, no previous CT studies have been able to use the lateral angle method to predict sex with any degree of reliability (Akansel 2008; Morgan 2013). At best, this study was able to predict sex 73% of the time in age group 4 using the anterior lateral angle, but no degree of reliability could be obtained in other age groups. The casting method obtains lateral angle measurements indirectly by bisecting a cast of the negative air space of the internal auditory canal. The measurement is then obtained by estimating the angle of the cast based on its position on the protractor to the nearest 5°. The combination of inaccurate impressions, casting material shrinkage, and imprecise protractor measurements may account for the differences in results.

The CBCT method used here measures the lateral angle directly off of the bone and the lateral wall of the internal auditory canal using a 2-dimensional slice of the internal acoustic canal. This method obviates the potential measurement precision issues related to inaccurate casting techniques and inflated angle sizes. The largest difference between the two methods is that the measurement tools provided by InVivo 5.3 obtains the lateral angle to 2 decimal places rather than rounding to the nearest 5° increment. It is possible that this difference in methodology had an effect on the size of the lateral angle measured and may explain the differences in sex determination accuracy between the current study and prior published literature. Another potential source of measurement error was the placement of the points used to connect the lines used in measuring the lateral angle. As the lateral walls of the internal auditory canal are seldom straight, but rather curved and irregular in surface quality, measurement inconsistencies and errors may have been present.

No relationship was found between the anterior or posterior lateral angle and age, both when the sexes were combined and when controlling for sex. This is inconsistent with Morgan's (2009) study but consistent with the findings of Akansel et al. (2008) and Graw et al. (2004). While Morgan did not find a significant relationship between lateral angle size and age, she did note a trend with an increase in lateral angle size with the progression of age. This is contrary to the findings in this study, where no trend was found between mean lateral angle size and progression of age.

## The Diameter Method

The second objective of this study was to evaluate sex differences in the diameter of the internal auditory canal at four sectioning points along its entire length 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 of the opening yields less precise measurements. Lynnerup et al. (2006) took note of this issue and recommended future studies use more advanced morphometric analyses using image-based measurements. It was the goal of this study to apply such an image-based analysis using CBCT images of the internal auditory canal to achieve more precise measurements.

In 2009, Morgan attempted to validate Lynnerup's study by applying a CT method to measure the diameter of internal acoustic meatus. Morgan measured the diameter from the anterior to posterior wall by placing measurement points along the bony edges of the canal, which resulted in much higher diameter measurements than Lynnerup (2006). In addition, Lynnerup's drill method was limited by the vertical diameter, which would have prevented the insertion of a larger drill even if the horizontal diameter were significantly larger. Due to CT scanner anisotropy, Morgan was only able to obtain the horizontal diameter using the same image in which the lateral angle was measured.

The present study used CBCT images, which do not suffer from this limitation as the voxels are isotropic. Thus, a custom section of the internal auditory canal was made along a plane connecting the anterior and posterior lips of the internal auditory meatus. As the shape of the peripheral walls of the internal auditory canal was seldom circular, the single largest diameter in any orientation was recorded at each of the four predetermined sectioning points used in this study. Consistent with Morgan's (2009) study, this accounted for much larger diameter measurements in the present study compared to those reported by Lynnerup (2006); thus Lynnerup's sectioning points could not accurately predict sex nor could they be adequately tested for validity in sex determination. However, sexual dimorphism in the diameter of the internal auditory canal at each of the four predetermined sectioning points (2 mm, 4 mm, 6 mm, and 8 mm lateral to the internal acoustic meatus) within each age group was able to be tested. Previous studies (Lynnerup et al. 2006; Morgan 2009) have examined sexual differences in the diameter of the opening of the internal auditory meatus, but none have evaluated diameter measurements that extend more laterally into the canal.

Frequency tables were constructed to analyze any potential sex differences in diameter size distributions at each sectioning point among all age groups. In analyzing the frequency tables, it was observed that the diameter of internal auditory canal at 2 mm and 4 mm exhibited a similar distribution of measurements between males and females; however, the diameter at 6 mm and 8 mm appear to have slightly different distributions, with females tending to have slightly smaller diameter values than males. This is consistent with Morgan's (2009) finding of the diameter distributions at 1 mm and 2 mm.

When analyzing sexual differences in diameter within each age group, there were no significant differences found for any of the diameter measurements in age groups 1 and 3. Interestingly, a significant difference in diameter was found at 6 mm ($p = .003$) and 8 mm ($p = .023$) in group 2. The mean difference was 4.6 mm for the diameter at 6 mm and 6.5 mm for the diameter at 8 mm. In group 4, a significant difference was found in the diameter at 4 mm ($p = .048$) and 6 mm ($p = .039$). The mean difference was 6.2

mm for the diameter at 4 mm and 8.7 mm for the diameter at 6 mm. In group 5, a significant difference was only found in the diameter at 6 mm ($p$ = .001), with a mean difference of 6.1 mm. Overall, the diameter of the internal auditory canal at 6 mm lateral to the opening seemed to exhibit the greatest sexual dimorphism in each age group. The mean differences exhibited in this study are much larger than the mean differences reported for the diameter of the opening in Morgan (2009) and Lynnerup's studies, which at best was only 0.36 mm. While this is promising, the results may be biased due to the smaller samples sizes and uneven sex distributions in group 4 (15 males, 7 females) and group 5 (5 males, 8 females). This indicates a need for further studies with larger sample sizes and even sex distributions to evaluate sexual differences in diameters along the length of the entire auditory canal.

In an analysis of the relationship between age and the diameters of the internal auditory canal, a weak negative correlation (r = -.139) reached statistical significance at 4 mm ($p$ = .022) when both sexes were combined. When controlling for sex, a weak negative correlation reached statistical significance at 2 mm (r = -.171; $p$ = .045), 4 mm (4 = -.166; $p$ = .033), and 6 mm (r = -.185; $p$ = .024). No relationships between age and diameter were found in males. This suggests that there may be an age-related change in the size of the diameter in females. This contradicts Morgan's (2009) finding of no age-related change in the size of the diameter in females at 2 mm. Overall, it appears that the diameter of the internal auditory canal decreases with age, which agrees with Morgan's (2009) findings.

## The Area Method

The third objective of this study was to develop an additional CBCT method to measure the cross-sectional area of the internal auditory canal in order to predict sex in subadults. No previous studies have evaluated sexual dimorphism using area measurements of the internal auditory canal. This is probably due to the limitations inherent in CT scans due to voxel anisotropy, which results in accurate measurements being possible only in the axial plane. In accordance with the four sectioning points chosen for the diameter measurements, the cross-sectional area was measured at 2 mm, 4 mm, 6 mm, and 8 mm lateral to the internal acoustic meatus.

Frequency tables were constructed to analyze any potential sex differences in area size distributions at each sectioning point among all age groups. In analyzing the frequency tables, it was observed that females tended to have smaller area values than males at each of the four sectioning points.

When analyzing sexual differences in area within each age group, there were no significant differences found for any of the area measurements in age groups 1 and 5. Interestingly, a significant difference in area was found at 2 mm ($p$ = .044), 4 mm ($p$ = .048), 6 mm ($p$ = .007), and 8 mm ($p$ = .003) in group 2. The mean differences were 4.2 $mm^2$ for the cross-sectional area at 2 mm, 4.0 $mm^2$ at 4 mm, 4.6 $mm^2$ at 6 mm, and 6.5 $mm^2$ at 8 mm. In group 3, a significant difference was found in the area at 2 mm ($p$ = .025) and 4 mm ($p$ = .046). The mean difference was 6.2 $mm^2$ for the area at 2 mm and 4.3 $mm^2$ for the area at 4 mm. In group 4, a significant difference was only found at 6 mm ($p$ = .013) and 8 mm ($p$ = .043). The mean difference was 8.7 $mm^2$ for the area at 6 mm and 6.4 $mm^2$ for the area at 8 mm. Overall, the area of the internal auditory canal seems to exhibit significant sexual dimorphism in most age groups. While this is promising, the results may again be biased due to the smaller samples sizes and uneven sex distributions in group 4 (15 males, 7 females). This indicates a need for further studies with larger sample sizes and even sex distributions to evaluate sexual differences in cross-sectional areas along the length of the entire auditory canal.

In an analysis of the relationship between age and the areas of the internal auditory canal, a weak negative correlation reached statistical significance at 2 mm (r = -.163; $p$ = .013), 4 mm (r = -.196, $p$ = .001), and 6 mm (r = -.152, $p$ = .016) when both sexes were combined. When controlling for sex, a weak negative correlation reached statistical significance at 2 mm (r = -.198; $p$ = .020), 4 mm (r = -.229; $p$ = .003), and 6 mm (r = -.199; $p$ = .015) in females. A weak negative correlation also reached statistical significance in males, but only at 4 mm (r = -.190; $p$ = .048). This suggests that there may be an age-related change in the size of the area in males and females.

**Logistic Regression Analysis**

The statistical analyses of the anterior and posterior lateral angles did not reveal any statistically significant sex differences in any age group, but some diameter and cross-sectional area measurements did demonstrate statistically significant sex differences in certain age groups. The final step in this research was to use logistic regression analysis to directly model sexual dimorphism for each age group evaluated in this study sample. Since age group 1 did not demonstrate any statistically significant sex differences for any of the methods used in this study and group 5 had a very small sample size, binary logistic regression analysis was only performed for groups 2 through 4.

The formula created using logistic regression incorporated eight diameter and area measurements of the internal auditory canal and was the most accurate method in this study for sex determination. The formula created for sex prediction was:

**Group 2 and 3**

$$\text{Log-odds} = A + B_1(\text{Diam } 2) + B_2(\text{Diam } 4) + B_3(\text{Diam } 6) + B_4(\text{Diam } 8) + B_5(\text{Area } 2) + B_6(\text{Area } 4) + B_7(\text{Area } 6) + B_8(\text{Area } 8)$$

**Group 4**

$$\text{Log-odds} = A + B_1(\text{Diam } 4) + B_2(\text{Diam } 6) + B_3(\text{Area } 6) + B_4(\text{Area } 8)$$

Where A is the constant and B values are the coefficients. The formula finds the log-odds value which is then used to determine the odds by taking the exponent of the log-odds. Sex determination is based on probabilities, however, and the odds value must then be used to determine the probability. This probability will always fall between 0 and 1 and is a measure of how likely an event is to occur or not occur. The event in this analysis is actually sex set up as a binary outcome with females scored as 0 (not occurring) and males scored as 1 (occurring), making probabilities above .5 more likely to be male and those below .5 to more likely be females. The strength of the probability of correct sex determinations increases as values approach 0 and 1.

As an example of the use of this formula, case #4872 was randomly selected. The values for this individual are:

| | |
|---|---|
| Diam 2: 9.22 | Area 2: 23.74 |
| Diam 4: 6.82 | Area 4: 20.89 |
| Diam 6: 6.20 | Area 6: 26.00 |
| Diam 8: 6.16 | Area 8: 24.11 |

The constants and coefficients used in this equation are based on the logistic regression output. The formula would follow as:

$$\text{Log-odds} = -7.199 + .423(9.22) + .056(6.82) - 1.259(6.2) + .563(6.16) - .036(23.74) + .084(20.89) - .116(26) + .354(24.11)$$

$$\text{Log-odds} = -0.83568$$

$$\text{Odds} = e^{-0.83568} = 0.4338$$

In order to determine whether an individual is male or female, a probability is required so the odds value must be changed to probability using the formula:

$$\text{Probability} = \text{Odds}/(\text{Odds} + 1)$$

$$\text{Probability} = 0.4338/(0.4338+1) = .302$$

The probability for this individual is .302, which means the individual is likely female as the cut-off value for determining sex is .5. After it was determined that this individual was likely female, the demographic information was examined and case #4872 was in fact female.

Using this logistic function model, sex was correctly allocated in 85.3% of all cases in group 2, with a predictive value of 90.5% for females and 76.9% for males. The cross-sectional area at 8 mm was the only variable found to be statistically significant (*p*

= .012) in the logistic function equation for group 2. In the logistic function model for group 3, sex was correctly allocated in 84.8% of all cases, with a predictive value of 82.4% for females and 87.5% for males. The diameter at 6 mm ($p$ = .020) and the cross-sectional area at 6 mm ($p$ = .039) were the only variables found to be statistically significant in the logistic function equation. In group 4, the logistic function model was formed using only the diameters at 4 mm and 6 mm and the cross-sectional areas at 6 mm and 8 mm. Sex was correctly allocated in 88.2% of all cases, with a predictive value of 90.9% for females and 83.3% for males. Despite this high sex prediction accuracy, none of the four predictor variables were found to be statistically significant in the final equation.

Overall, these results are promising and meet both Novotný et al.'s (1993) criteria for very reliable (>60% correctly classified, <10% misclassified) sex determination traits (Table 2.1) as well as 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. The logistic regression model presented here also adheres to Albanese' (2003) minimum criteria of 85% accuracy for usefulness in determining sex. Thus, after exclusion of the lateral angle method, both of the null hypotheses can be rejected for age groups 2, 3, and 4. For group 1, the null hypothesis was accepted, and for group 5, the sample size was too small to conclude whether or not to reject the null hypothesis. Consequently, morphometric measurements of the diameter and cross-sectional area of the internal auditory canal, as measured on a CBCT scan, will identify the sex of subadults age 11-19 with an accuracy equal to or greater than 85%.

## Implications and Limitations

Traditionally, anthropological measurements of skeletal elements were made using simple rulers, calipers and goniometers. While these methods were simple and did not require any special equipment or software, the measurements that were able to be recorded were limited and often imprecise. The cadaveric method, including the negative cast (Graw et al. 2005, Gonçalves 2011, Noren et al. 2005) and drill end methods (Lynnerup et al. 2006), suffered from problems with inaccurate impressions, casting material shrinkage, as well as somewhat crude measurement errors. The present study modified these prior methods to apply 2-dimensional image based measurements directly onto the bony surface of the skull using a forensically modern sample of CBCT scans of subadult skulls. By using these image-based measurements with software that allows for custom sections to be created in any plane, the possibilities for new measurement parameters are unlimited. In addition, the values are precise up to 2 decimal places and advanced measurement tools allow for more complex measures to be calculated, such as area. Since the combination of diameter and area proved to provide the highest accuracy in correct sex allocation, this shows a potential area for future research using 3-dimensional volumetric methods. Currently, Invivo 5.3 software is capable of automatically calculating the nasopharyngeal airway volume and the minimum cross-sectional area. A new algorithm could potentially be written to calculate the volume of the internal auditory canal as well as measure cross-sectional areas at predefined sectioning points.

One of the major limitations of this study was directly related to the adequacy of the CBCT data that were used to analyze the internal acoustic canal. The canal is an extremely small structure within the skull and once the image is zoomed in, imaging artifacts become more apparent. While every effort was made to exclude samples in which the internal auditory canal and its apex was not clearly visible, not every artifact could be avoided. Such artifacts include, but are not limited to, noise and the exponential edge gradient effect (EEGE) (Kincade 2011; Schulze et al. 2011). Noise is one of the most common artifacts in CBCT imaging and presents as inconsistent attenuation values in the projection images, or a “graining” of the image (Kincade 2011). The EEGE is the CBCT equivalent of the partial volume effect in CT. According to Schulze and colleagues (2011), this affect appears at sharp edges with high contrast to neighboring structures. The sharp edges appear “blurred” due to the scanner being unable to differentiate between a small amount of high-density material, such as the petrous portion of the temporal bone, and a larger amount of lower density material, such as the soft nerve tissue within the internal acoustic canal (Kincade 2006). When the processor tries to average out the two densities or structures, information is lost and the CBCT image created is not representative of either tissue type (Kincade 2006). The effects of this edge blurring made it difficult to clearly delineate the bony edges representing the walls of the internal auditory canal when plotting the points that were used to calculate area and diameter measurements. In addition, compared to CT, CBCT has less dynamic range and contrast, which would create a sharp interface between the bony walls of the canal and air (Scarfe and Farman 2008). These factors may have limited the accuracy of the measurements used in this study.

A second major limitation of this study was the limited sample size in each age group and unequal distribution of males and females (

Table *4.4*). The distribution was relatively even in group 2 (59 females, 50 males) and group 3 (42 females, 37 males), but there was a strong female bias in group 1 (39 females, 12 males), group 4 (15 females, 7 males), and group 5 (10 females, 5 males). Consequently, the results for groups 1, 4, and 5 may not be reliable and further studies with larger samples sizes and an equal number of males and females are needed. It is also recommended that future studies examine CBCT data from several different populations in order to better understand the possible inter-population variation in the sexual dimorphism of the internal auditory canal.

Another potential reason why statistically significant differences between males and females were not found in group 1 (age 6-10) is because the onset of puberty, and therefore the development of sexually dimorphic characteristics, is unlikely to have begun. While there is enormous individual variation, girls tend to begin puberty between the ages of 10 and 13 with boys experiencing pubertal onset 2 years later. A precocious female may experience pubertal onset as early as age 7 or 8. Puberty ends about 8 to 10 years after it starts, when the person is physically mature and capable of reproduction. The large variation in the age of pubertal onset may explain the lack of sexual dimorphism found in group 1.

As it is entirely possible for an early-maturing boy to reach pubertal onset ahead of a slow-maturing girl, it must be remembered that chronologic age is a crude indicator of where an individual stands developmentally. To accurately identify an individual's stage of development, a diagnosis of skeletal age is needed. This study evaluated sexual dimorphism of the internal auditory canal in groups based on chronological age without identifying skeletal age. As a result, the conclusions for each age group study may become deficient or enhanced after skeletal age is accounted for. Further research to correlate chronological age, skeletal age, and measurements of the internal auditory canal are warranted.

## Conclusion

This study demonstrates that CBCT image-based data of the petrous portion of the temporal bone may be used to predict the sex of skeletal remains in subadults. The lateral angle method, using either the anterior or the posterior lateral angle, failed to predict sex reliably. Correct sex allocation accuracy of less than 60% was obtained in most age groups. At best, the anterior lateral angle method was able to correctly allocate sex 73% of the time in subadults age 17 – 19. No statistically significant differences were found for the lateral angle in any group. Statistically significant differences in diameter and/or area were found in individuals age 11-24 (Groups 2 – 5). Both diameter and area measurements tended to be larger in males than females and had a tendency to decrease with age. Using a combination of the diameter and area methods, logistic function models were able to correctly allocate sex with an accuracy of 85.3% for 11 – 13 year olds, 84.8% for 14 – 16 year olds, and 88.2% for 17 – 19 year olds. These results represent exciting findings in the field of anthropological research regarding adolescents and may encourage anthropologists to collaborate with radiologists to further examine the potential of biomedical imaging in anthropological research.

Appendix A

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**Biomedical IRB**
**Notice of Excluded Activity**

| | |
|---|---|
| **DATE:** | May 6, 2014 |
| **TO:** | **Dr. James Mah,** School of Dental Medicine |
| **FROM:** | Office of Research Integrity – Human Subjects |
| **RE:** | Notification of IRB Action<br>Protocol Title: **Internal Auditory Canal Analysis Using Archival Dental Records**<br>Protocol# 1405-4805M |

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This memorandum is notification that the project referenced above has been reviewed as indicated in Federal regulatory statutes 45CFR46.

The protocol has been reviewed and deemed excluded from IRB review. It is not in need of further review or approval by the IRB.

*Any* changes to the excluded activity may cause this project to require a different level of IRB review. Should any changes need to be made, please submit a Modification Form.

If you have questions or require any assistance, please contact the Office of Research Integrity – Human Subjects at IRB@unlv.edu or call 895-2794.

Office of Research Integrity – Human Subjects
4505 Maryland Parkway • Box 451047 • Las Vegas, Nevada 89154-1047
(702) 895-2794 • FAX: (702) 895-0805

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Curriculum Vitae

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## EDUCATION

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2012 Fellowship, Advanced Education in Orthodontics and Dentofacial Orthopedics, University of Nevada, Las Vegas

2011 DDS, University of the Pacific Arthur A. Dugoni School of Dentistry, San Francisco, California

2008 B.S. Biological Science, University of the Pacific, Stockton, California

2006 A.S. Chemistry, Tacoma Community College, Tacoma, Washington

## PUBLICATIONS, RESEARCH PRESENTATIONS AND PROJECTS

2010 ***Poster Presentation.*** Methylenetetrahydrofolate Reductase C677T Polymorphism and Nonsyndromic Cleft Lip and Palate.

AADR San Francisco Section 3rd Annual Scientific Meeting. San Francisco, California.

88th IADR General Session. Barcelona, Spain.

2010 ***Poster Presentation.*** Reduced Folate Carrier 1 Polymorphism and Nonsyndromic Cleft Lip and Palate.

CDA Table Clinic. Anaheim, California.

Pacific Research Day. San Francisco, California

AADR General Session, San Diego.

2010 **Contributing Editor.** *Dental Board Busters for NBDE Part I*, Second edition, Braintree Publishing

2010 AdoHcy hydrolase of Trichomonas vaginalis: Studies of the effects of 5'-modified adenosine analogues and related 6-N-cyclopropyl derivatives. *Bioorganic & Medicinal Chemistry Letters.*