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Forensic Medicine

THE PARANASAL AIR SINUSES IN THE HUMAN:

An Anatomical Assessment using Helical Multislice Computed Tomography.

Applications to Human Forensic Identification.

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DECLARATION

I, Carmen Lee Fernandes, confirm that the research included within this thesis is my own work or where it has been carried out in collaboration with, or supported by others, that this is duly acknowledged below and my contribution indicated. Previously published material is also acknowledged below.

I attest that I have exercised reasonable care to ensure that the work is original, and does not to the best of my knowledge break any UK law, infringe any third party's copyright or other Intellectual Property Right, or contain any confidential material.

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Date: 6 January 2016

Details of collaboration:
DR. W.H. Moolman PHD, Statistician, South Africa provided statistical Assistance.
Limited Statistical Assistance (in part only) provided by Dr. Ryan Butterworth, PHD, Statistician USA.

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ABSTRACT

Introduction: Forensic pathologists may be asked to identify the race group or sex of a cranium of unknown origin. Race group refers to geographic ancestry and sex is biological sex.

An analysis of the volumes and measurements of human paranasal sinuses, namely maxillary, ethmoid, sphenoid and frontal sinuses, in dried crania of different race and sex groups (European and Zulu male and female) was undertaken to search for a new improved approach of classifying crania according to race and sex. This anatomical assessment of the human paranasal sinuses identifies race and sex variations in the paranasal sinuses. Variations in paranasal sinus volumes and measurements may mean a variation in anatomical landmarks. The best combination of sinus measurements was selected to classify a cranium according to race group and sex making this research relevant to the field of forensic medicine.

Objectives: To compare the paranasal sinus volumes and measurements of dried crania of European and Zulu descent with respect to race group and sex and to develop a method of classifying a cranium according to race group or sex by using dimensions of the paranasal sinuses.

Methodology: Documented, cadaver derived, dried crania were obtained from the Raymond A. Dart Collection of Human Skeletons, housed at the School of Anatomical Sciences at the University of the Witwatersrand, Johannesburg, South Africa. Age, race and sex were recorded for each cranium within the collection and hence within the study sample. 26 Adult European crania; 13 male, 13 female. Age range 19-75yrs (mean 49.42yrs) and 27 Adult Zulu crania: 13 male, 14 female. Age range 16-90yrs (mean 40.16yrs) was selected for this study. An additional cranium of unknown origin was also analysed in the research.

European crania were from descendants of Europe living in South Africa and Zulu crania were obtained from Zulu patients who were part of the Zulu tribe of South Africa.

53 crania with intact paranasal sinuses (106 individual sinuses for each of the maxillary, ethmoid, sphenoid and frontal sinuses) were studied. In addition, 2 sinuses from the unknown cranium were analysed.

The dried crania of European and Zulu origin were assessed by helical, multislice computed tomography using 1mm coronal slices. The area for each slice was obtained by tracing the outline of each slice. A volume was calculated by the CT machine that totaled the slices for each sinus. Measurements of width, length and height were also assessed, as were other craniometrical measurements. Statistical analysis was performed for all European and Zulu male and female sinuses in respect of volumes and measurements. Further statistical analysis searched for classification patterns.

In addition, forty patients' scans from the European and Zulu male and female groups in Southern Africa were also assessed. CT scans of 10 adult European males, 10 adult European females, 10 adult Zulu males and 10 adult Zulu females provided 40 pairs of maxillary, ethmoid, sphenoid and frontal sinuses for analysis. Europeans were South African persons of European descent and Zulus were from the Zulu tribe of Kwa Zulu Natal in South Africa.

Results: The aim of identifying race and sex differences in this anatomical region is achieved. Significant race and sex variations were found in the European and Zulu, male and female groups when analysing the volumes and measurements of the paranasal sinuses. The very best combinations of classifiable measurements were described and are being put forward as a new tool in human forensic identification studies. The significant sex classification figure of 91.8% by combining ethmoid, sphenoid and frontal paranasal sinus measurements, is a new discovery for using a combination of the sinuses. The significant race classification figure of 95.9 % is an excellent classification figure for classification according to race. This was done using the measurements of maxillary, ethmoid and total distance across the sinuses. All this was achieved by using the measurements of the paranasal sinuses in a European and Zulu, male and female population.

Conclusion: Forensic race and sex identification of crania is now possible using a combination of measurements from the paranasal sinuses. A new approach to classifying a cranium into an race or sex group is revealed by way of using a new combination of paranasal sinus measurements. This discovery is of importance to forensic medicine in the realm of identification as it provides a measurable way of assigning race or sex to a cranium within a particular region. Other studies based on other race groups may add further value. What is clear is that the paranasal sinuses are now of established value when assessing race or sex group of a unknown cranium. A new tool for forensic race and sex identification is provided to the armamentarium of the forensic pathologist and associated disciplines.

CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION TO THE PRESENT STUDY

This study is a research analysis into the paranasal air sinuses in the human. It is an innovative study that began with the author's interest in the varying volumes and measurements of the maxillary sinus cavities between persons of European and Zulu descent in Southern Africa. It is an analysis of all the human paranasal sinuses in respect of volumes and measurements and the applications are applied to forensic medicine. This was a field that had not been researched much before, save for the early anatomists. No practical applications previously had been found for apparent differences in the sinuses and so this research was designed with the aim of establishing differences in paranasal sinus volumes and measurements between different race and sex groups. By race we mean geographic ancestry and by sex we mean biological sex. In so doing, the aim was to establish a place in forensic and clinical medicine for these findings.

In forensic medicine, with decomposition, the skull may be the last remaining part of the skeleton available to analyse. The skull itself is fairly resistant to decomposition and so it becomes important to find methods to correctly derive race group and sex from it. The classification of a cranium according to race and sex is of great value in human identification. This research aims to contribute to this.

The basis of this study is the hypothesis that there are race and sex differences in the paranasal sinus volumes and measurements of dried crania of European and Zulu origin. The null hypothesis is that there are no race and sex differences in the paranasal sinus volumes and measurements of dried crania of European and Zulu origin.

The aim of this research is to provide a new way to use paranasal sinus volumes and measurements to classify crania of different race and sex groups; in this case European and Zulu populations. And, in so doing, provide additional methodology to the field of human identification by establishing the value of assessing paranasal sinus volumes and measurements for use in identification of human remains. In addition, anatomical variations gleaned from this cadaver study may have relevance for surgical fields and thus enhances the importance of forensic research to clinical medicine.

In order to test this hypothesis, a research project was devised and undertaken.

This research is a unique, original, comparative study of the volumes and measurements of the maxillary, ethmoid, frontal and sphenoid sinuses in European and Zulu crania.

Computed Tomography was selected to investigate sinus volume because it is an advanced radiographic method chosen by current researchers and is so reflected in the literature. Helical Computed Tomography is an accurate method available to measure sinus volume and an ideal choice to accurately take measurements of the human paranasal sinus cavities.

A variation in the volume of the maxillary, ethmoid, sphenoid and frontal sinuses between persons of European descent and those of Zulu origin would confirm variations in the anatomy of the respective race groups. For the purpose of this research, this variation in volume will be investigated in conjunction with measurements taken of the sinus cavities. It's value for forensic medicine will be investigated.

In addition, surgical implications of the findings may be considered, as such a cadaver study may reveal anatomical variations that are significant for surgical procedures. Ultimately, a variation in anatomy may have clinical implications that may modify surgical and medical techniques. In this way, this research aims to highlight the importance of forensic medical research and how such findings can be applied to clinical medicine. Hopefully significant findings emanating from forensic research would give strength for the need for funding of research in academic forensic medicine.

This study has relevance for forensic pathologists, anthropologists, anatomists, maxillo-facial surgeons and other medical scientists.

The crania used in this research project were obtained from the Raymond A. Dart collection of Human Skeletons in the Department of Anatomy, University of Witwatersrand, Johannesburg, South Africa. The Computed Tomography was executed on a Toshiba Asteion Helical Multislice scanner at the Linksfield Park Clinic in Johannesburg. South Africa. The venue was selected due to proximity to the crania.

By the sequential addition of areas from 1mm computed tomographic slices, a volume was calculated for each maxillary, ethmoid, sphenoid and frontal sinus. In order to permit a more unique analysis of these anatomical cavities, additional measurements of width, length and height were taken. Geometric, mathematical and statistical techniques were applied where appropriate to analyse and classify the data. As the maxillary sinus was the most accessible and easiest to measure it was the ideal sinus to make a model of. In a preliminary study of the maxillary sinus it was established that this sinus was most suitable to perform a shape analysis on. A three dimensional model of the maxillary sinus was created by injecting dental silicone into the maxillary sinus. This was performed on an unclassified skull, which was made available for destruction. The two maxillary sinus models were assessed in respect of volume by the technique of water displacement. This aspect of the study was conducted at a dental laboratory under the supervision of a prosthedontist, a sinus surgeon and a dental technician.

Additionally, data from 40 live patient scans from the differing race and sex groups was acquired with the permission of the ethics committee, anonymised and analysed for differences in the paranasal sinus measurements and volumes. These were scans from South African white patients and South African black patients- predominantly representing European and Zulu groups. This was undertaken to look for race and sex variations in the paranasal sinuses and to see if these findings support the findings of the original cadaver study.

Maxillary, ethmoid, sphenoid and frontal sinus volumes and measurements of length, width and height were statistically analysed to look for variations between the differing race and sex groups. Discriminant analysis was performed. Race, sex and race sex interaction was assessed for all the sinus measurements.

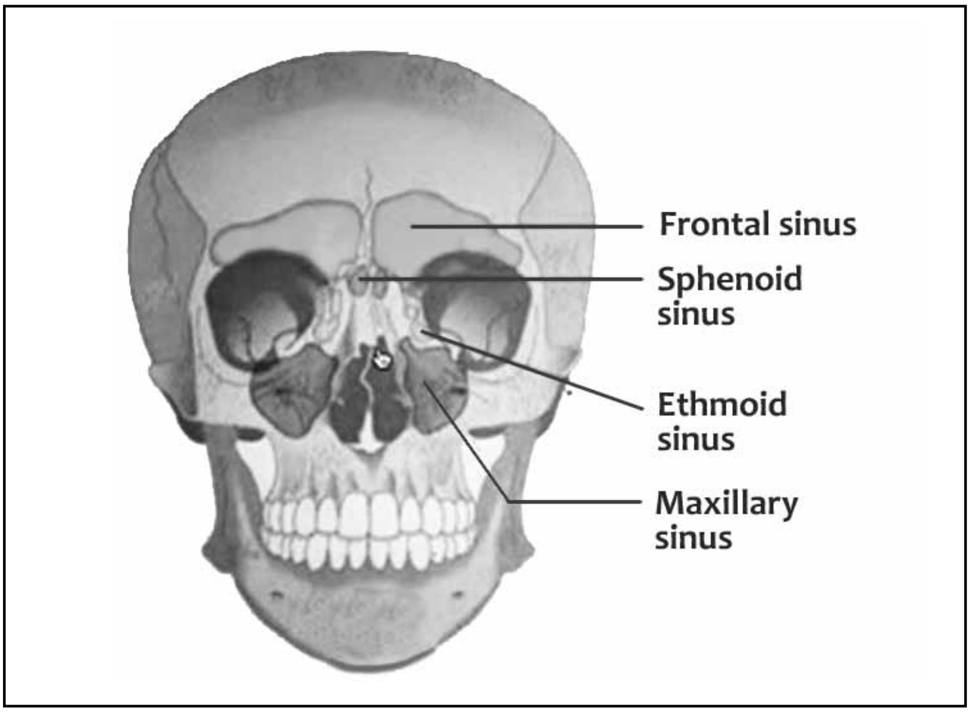
The research was extended to create classification formulae. This analysis involved additional craniometrical measurements and allowed for the creation of new formulae to predict raceity and sex from an unknown cranium. The formulas are significant for their ability to predict race and sex from the sinus measurements.

The significant clinical implications of this cadaver study are discussed and its direct relevance to clinical medicine is addressed. The predictive role of the sinus measurements in race and sex classification is established and the value of these findings to the field of forensic medicine, particularly human identification is discussed.

The aim of identifying race and sex differences in this anatomical region is achieved.

The relevance to the field of forensic pathology possibly yields a new technique for the race and sex classification of unidentified crania. The value to forensic medicine is that the race and sex differences in the human paranasal sinuses play an important role in the field of human forensic identification.

FIGURE 1.1 PARANASAL AIR SINUSES OF THE HUMAN



CHAPTER 2: LITERATURE REVIEW

2.1 HISTORICAL BACKGROUND

2.1.1 Origins of the Present Study

Historically, there is little information available on the anatomical and volumetric analysis of the human paranasal sinuses despite the fact that they are large pneumatised cavities forming an integral part of the cranium, which itself, has been studied throughout the ages. The maxillary sinus, the largest and most pneumatised of the paranasal sinuses, has been the subject of some early volumetric and anatomical studies. Several authors have described the anatomy of the maxillary sinus (Schaeffer, 1910; Hamilton and Harrison, 1952; Lund, 1997) and it has been the subject of human anatomical research (Onodi, 1905; Negus, 1958; Anagnostopoulou, 1991; Uchida, 1998). The frontal sinuses have been well recognised for their uniqueness of shape and form throughout the ages and hence for their role in human identification. The significance of frontal sinus variation has been recognised since the early part of the century (Turner, 1901; Cryer, 1907). The significance of the ethmoid complex and sphenoid sinuses historically has not been studied to the same extent.

Earliest literature pertaining to paranasal sinus anatomy dates as far back as Galen (130–201 A.D.). Galen first described the "porosity of the bones of the head" (Blanton and Biggs 1969). Wright (1914) acknowledged Berengar (1507–1527) for being the first to establish the existence of facial sinuses. Flottes, et al (1900), was quoted by Blanton and Biggs (1969) and recognised Leonardo da Vinci (1452–1519) as the discoverer of the sinuses of the face. Da Vinci, whose classical sections of the head illustrate the maxillary and frontal sinuses, described maxillary sinuses as being "equal in depth to nose and mouth" and "having a height of one third of a man's face from chin to hair" (O' Malley and Saunders 1952) as cited by Wolfowitz (1974).

Versalius (1542) described the paranasal sinuses and alleged that they contained nothing but air. Fallopius (1600) observed that they were absent in the crania of neonates (Wright 1914). The first anatomical description anatomy of the maxillary sinus was provided by Nathaniel Highmore (1651).

Early literature on the paranasal sinuses was focused on anatomical descriptions of the sinus cavities.

2.1.2 Early Volumetric And Measurement Studies Of The Human Paranasal Sinuses.

Simple volumetric studies of the sinuses were conducted by anatomists from as early as the nineteenth century (Braune & Classen, 1877; Schurch, 1906; Mundnich, 1937). The early studies assessed the paranasal sinus volumes by making casts of the sinuses of cadavers using substances such as beeswax or plaster and then measuring their volumes by the technique of water displacement. Boyne (1926) used beeswax and paraffin to prepare casts of the maxillary sinuses and assessed their volumes by weighing them in water and air (Wolfowitz, 1974). It is not possible to establish the accuracy of the volumes obtained by the early authors but the difficulties of working with a substance such as beeswax, in which you can easily get air pockets or miss filling in recesses, must be borne in mind. In addition, the cylinders for the water displacement techniques would almost certainly not be calibrated as well as those cylinders that exist today.

Another early technique used for measuring the volume of an anatomical cavities such as the paranasal sinuses, is performed by filling the cavity with sand or seed and then measuring the volume of the substance once it was removed. Koranne and Monteiro (1963), when studying population differences in the maxillary sinuses, used this technique of filling the maxillary sinus cavity with finely grained sand. The sand was then poured into a measuring cylinder in order obtain a volume of the sand. This volume translated to a volume of the maxillary sinus. The accuracy of the results obtained would be based on the how compact the sand in the sinus actually was as small air spaces between particles represent error in the measured volumes due to a variation in compaction. The sealing of the ostia, whilst ensuring that the sinus is maximally filled with sand, is also a site for potential error.

Other 20th century authors that researched the volumes of the maxillary sinuses of dry crania were Bezold (1943) and Schumacher (1972). By making casts of the maxillary sinus Bezold obtained an average sinus volume of 13.9 cm3 for 204 sinuses. Schumacher similarly obtained an average maxillary sinus volume of 9 cm3 for 16 sinuses. It is not possible to speculate the reason for this variation in volume due to the fact that Belzold’s and Schumacher’s sample size differs so significantly. The abovementioned crania were all of European descent.

Turner (1922) investigated population differences in frontal sinuses of 1000 crania of various races of mankind which included Eskimos, Aborigines, African Negroes, Polynesians, American Indians and mixed European races, with largely negative results. Brothwell, et al (1968) studied the normal variation of the frontal sinus by direct observation of antero-posterior radiographs of African Negro (Ibo), Australian Aboriginal, British Bronze Age, and Saxon crania. Brothwell found some evidence of intergroup and intragroup variation in height, width and area of the frontal sinus in these populations. The Ibo crania had larger frontal sinuses and the Aboriginal sample had smaller frontal sinuses than the rest of the groups. These authors pointed out, however, that the samples sizes were too small to allow for definite conclusions (Wolfowitz 1974).

Buckland -Wright (1970) took measurements of the height, width and planimetric area of the frontal sinuses on postero-anterior radiographs of early British crania and found that the frontal sinuses of Romano–British and Medieval populations were significantly larger than those of Bronze Age and Saxon populations (Wolfowitz 1974). Koertvelyessy (1971) took measurements of the frontal sinus area on antero-posterior radiographs of Alaskan Eskimo populations and proposed that a relationship existed between low climatic temperatures and small frontal surface areas.

Wolfowitz (1974), in an unpublished thesis, performed a study on the pneumatisation of the skull of the South African Negro. This study used the technique of roentgenographic cephalometry to assess pneumatisation of the crania of the Natal Nguni and Caucasoid race groups. Wolfowitz found that a significant population difference was present between the maxillary sinuses of Caucasoids and Natal Nguni. He found no population difference in overall size of the frontal sinuses in theses two groups. He noted that the sphenoid sinus was more pronounced in Caucasoids than in Natal Nguni, and that the expansion of the ethmoid air cells anteriorly, posteriorly and superiorly was greater in the Natal Nguni (Wolfowitz 1974).

The aspect of Wolfowitz's research that is relevant to this research is the measurement of the volumes of the maxillary sinuses and his finding that the maxillary sinus was significantly larger in Caucasoid males than in Nguni males, and the maxillary sinus was significantly larger in Caucasoid females than in Nguni females. Such findings would support this research hypothesis that there are race and sex differences in the volumes of the maxillary sinuses of dried crania of persons of European and Zulu origin. However, on careful review of the abovementioned study, it is evident that due to the inaccuracies in radiographic measurements and of discrepancies in volumes the results must be treated with reserve. Wolfowitz x-rayed the crania in three planes using standard sinus views. He obtained a calculated volume by taking the square root of the areas of the three views multiplied together. Wolfowitz obtained an actual volume by filling a number of the sinuses with millet seed and measuring the volume of the millet seed once it was removed from the crania. He stated that a mathematical relationship between the calculated volume and the measured volume existed which was based on his findings that the calculated volumes were higher than the measured volumes in most instances. With modern computed technology, which is used for the current research, the inaccuracies of roentgenographic cephalometry- the geometric distortion of the image and the poor definition of anatomical landmarks- can be eliminated.

2.1.3 Clinical, Research And Forensic Applications From This Cadaver Study The Maxillary Sinuses:

In maxillofacial surgery and dental surgery the volume of the maxillary sinus is becoming increasingly important. With dental implant surgery it is sometimes necessary to graft bone into the floor of the maxillary sinus as the maxillae atrophy in the absence of teeth (Sailer 1989). In these procedures the maxillary sinus floor is augmented with autogenous bone prior to the placement of endosseous implants (Raghoebar, et al 1993). In this procedure it is beneficial to know the maxillary sinus volume as it aids in determining the graft bone volume before grafting the maxillary sinus floor (Uchida, et al 1998). Bone grafting in the maxillary sinus floor has been performed since about 1980 and a few authors have expressed interest in the maxillary sinus volumes. Uchida (1988) performed a cadaveric study of maxillary sinus size and related it to bone grafting in the floor of the sinus. Of interest to this research is Uchida's methodology and antral volumes. Solid casts of 59 maxillary sinuses were made using silicone dental impression material. The casts were removed and anteroposterior length, height and width of the maxillary sinus casts were recorded. The volumes of the maxillary sinuses were obtained by the technique of water displacement. A mean volume of 11.3 cm3 was obtained. It is of interest to this study that the cadavers were Japanese and therefore a single race group. Uchida also related the volumetric findings to age and dentition. Of interest to the current study is that no significant differences were noted in measurements based on side of skull, sex or age. Importantly, Uchida found no difference in the volume of the maxillary sinus in either the dentate or edentulous group. In a published response to Uchida's article (Kraut, 1998), the findings of a research project at the Albert Einstein College of Medicine confirm the findings of Uchida and show a lack of variability in the volume of the maxillary sinus based on skull side, sex or age. Sanchez Fernandez et al (2000), in a computed tomographic study, found that maxillary sinus volumes increase until 15 years of age and afterwards maintain similar values. Ariji et al (1994) also used computed tomography and found that the difference in right and left dentition had no influence on the maxillary sinus volume over the age of 20 years.

Anagnostopoulou et al (1991) made casts of the maxillary sinuses of 60 dry crania. Anagnostopoulou's research attempted to classify the maxillary sinus according to its geometric features. Obtaining the volume of the maxillary sinus was an integral part of the study. The average volume obtained for the maxillary sinus was 11.75 cm3. This volumetric result lies midway between the mean volumes obtained by Bezold (1943) and Schumacher (1972). It is of interest to this research that the dried crania were all of Hellenic origin and therefore a homogeneous race sample. As this research aims to investigate any race variation in the volumes of the maxillary sinuses (and the other paranasal sinuses), the volumes obtained by Anagnostopoulou's Hellenic sample may be useful from a comparative perspective.

Anagnostopoulou classified the sinus according to 4 basic solid shapes. This classification is based on the fact that the sinus is pyramidal in shape and the apex is more or less rounded depending on the extension into the zygoma. In other words, using the base of the pyramid as the medial wall of the sinus, Anagnostopoulou classified the sinus according to the shape of its apex. Actual volume divided by the product of the area of the base multiplied by height of the sinus results in the shape coefficient for the sinus. Anagnostopoulou used these shape coefficients in order to classify the sinuses into 4 shapes: conical/pyramidal; hyperboloid; paraboloid and semi-ellipsoid. The majority of sinuses were classifiable as hyperboloid and paraboloid. The relevance of this shape classification to the present study lies in the possibility that an race or sex variation in the volume of the maxillary sinus may also indicate an race or sex variation in the shape of the sinus and this will have significant implications for surgeons operating endoscopically in this area. A major drawback of Anagnostopoulou's research is that the classification was not related to computed tomographic or other radiographic investigations of the maxillary sinus and therefore cannot be used by clinicians on live patients. Anagnostopoulou was not able to demonstrate any clinical relevance for the shape classification.

The value of this current original research is that it will investigate if an anatomical race and sex variation exists between the maxillary sinuses of these South African groups.

The Frontal Sinuses:

The understanding of frontal sinus anatomy holds great importance for clinical and forensic medicine.

The significance of frontal sinus variation has been recognised since the early part of the century (Turner, 1901; Cryer, 1907). These irregularly shaped cavities located in the frontal bone have attracted attention largely because of their unique shape in individuals. The use of frontal sinuses for personal identification dates back to 1925 when Cuthbert and Law established 13 points of identity found in sinus prints as well as establishing variations in other accessory sinuses, the sella turcica and the mastoid process in order to establish the identity of a former patient (Reichs 1993). Subsequent to this numerous authors have used frontal sinus comparison for positive identification mostly by comparing ante mortem and post-mortem records.

Schuller in 1943 radiologically verified that the frontal sinuses are bigger in males than females and noted that the presence of a metopic suture is associated with absent frontal sinuses. In his early work, Schuller claimed that the radiographic outlines of the frontal sinuses of no two people are alike (Schuller 1921). The utilisation of x-rays of the head for the purpose of identification of individuals was continued by Singleton (1951), Thorne and Thyberg (1953), Cornwell (1956), Krogman (1962) and Vlcek (1968). In 1953, Schuller developed techniques for the anthropometric description of frontal sinus radiographs. Sassouni (1959) performed a cephalometric study on 500 adult males and performed linear measurements of head and face x-rays, which could be used for the identification of corpses and this method he claimed was 100% accurate (Wolfowitz 1974).

The variation in size of the frontal sinuses was later studied by Walander (1965), using planimetric measurement of the outlines of the frontal sinuses on postero- anterior x-rays of 600 adults.

In 1987, Yoshino et al, designed a system of classification of the frontal sinuses based on seven discrete variables: area size (left and right); bilateral asymmetry; superiority of area size; outline of superior borders; partial septa; supra orbital cells and orbital areas (Cameriere et al, 2008). Out of Yoshino's system, a class number is assigned to each morphological characteristic and the frontal sinus patterns of a given person are formulated as a code number. The Yoshino code number allows for personal identification. Several authors continue to study frontal sinus variation today. It can also be noted that one or both sinuses may be absent.

Much research has been performed on frontal sinus variation, yet less has been performed on the volumes of the frontal sinuses.

Clinical applications of frontal sinus volume and dimension studies are likely to benefit fields such as neurosurgery, where minimally invasive surgery has acquired growing importance. When cranial base surgery is performed in the frontal region or when a supraorbital mini craniotomy is performed, a sound knowledge of anatomical variations may avoid post-operative complications. Knowledge of frontal sinus anatomy and its variations is relevant for the diagnosis of sinus pathologies and for clinical and surgical procedures. In endoscopic sinus surgery, complications such as CSF leaks may be avoided. In this way, knowledge of anatomical variation between landmarks in differing race and sex groups will benefit surgeons operating in this region.

In forensic medicine, this research will add additional data to frontal sinus variation studies. An analysis of race and sex variation of frontal sinus volumes and measurements will be performed. As opposed to frontal sinus variation studies applicable to personal identification, this research will establish if any race or sex population differences exist in the frontal sinus, and if frontal sinus volumes and measurements–in combination with other paranasal sinus measurements–will add value to the field of human identification in respect of race and / or sex classification.

The Ethmoid and Sphenoid Sinuses:

Early literature pertaining to ethmoid and sphenoid volume and measurement studies is sparse.

The ethmoidal labyrinth demonstrates much variability and morphometric and geometric relationships of the medial wall, ethmoidal foramina and orbital apex will have relevance to surgeons operating in this area.

In forensic medicine, it is possible that race and sex differences exist in the ethmoid region. This may in itself hold value for human forensic identification and may in combination *with other paranasal sinus measurements be of value to aid classification of crania of unknown origin.*

The sphenoid sinus is extremely variable in size and shape and in relation to the sella. It is divided by vertical septa that are most often asymmetric. Sphenoid sinus variations between individuals is well recognised.

The sphenoid sinus displays varying degrees of pneumatisation and has been described as presellar, postsellar or conchal. The presellar type is situated in the anterior sphenoid bone, not penetrating the perpendicular plate of the tuberculum sellae; the postsellar type is well pneumatised and demonstrates bulging of the sellar floor into the sinus; the conchal type of sphenoid sinus does not extend into the body of the sphenoid bone, and the anterior wall is separated from the sella turcica by about 10mm of bone.

There are many surgical approaches to the sphenoid sinus, Intracranial, transeptal, transantral etc. *In recent years the transsphenoidal approach to the pituitary gland has become significant and the surgical anatomy of the spheroid sinus and its relationships, has become increasingly important (Sareen et al, 2005). Studies such as this, that review the dimensions and volumes of the sphenoid sinus are gaining importance in the literature.*

In forensic medicine, dimensions and volumes of the sphenoid sinus have not been investigated in respect of aiding classification of crania in terms of race group or sex. As with the ethmoidal labyrinth, the measurements obtained in this study may hold value for the field of human identification.

2.1.4 Theories Of Human Paranasal Sinus Function

The functional role of the paranasal sinuses has often been disputed. It is logical that the volumes of sinuses would be related to their function. A prominent feature of the maxillary sinus is its large volume. Prominent features of the frontal sinuses are their uniqueness in shape in individuals, but few studies exist on its volume and this also prevails for the ethmoid and sphenoid sinuses.

Future research into the function of the sinuses will most likely bear a direct relationship to their volumes and it can be extrapolated that race variations would be significant in this respect. The significance of these air spaces remain a continuing unresolved issue.

(i) Resonance Theory: Bartholinus (1660) proposed that sinuses were important in phonation by adding resonance to the voice (Rhys Evans, 1992). However, research has shown that lions have small sinuses but roar loudly (Proetz, 1953), and giraffes and rabbits have large sinuses but have weak voices (Negus 1958). Blaney (1990) points out that this theory has been discounted because the size of the sinuses bears little relationship to the strength of the voice (Rhys Evans, 1992).

(ii) Mucus Secretion Theory: It was suggested by Haller (1763) that the sinuses were important in moistening the olfactory mucosa (Rhys Evans, 1992). This theory was disputed because of a comparative lack of mucous glands in the mucosa of the paranasal sinuses (Negus, 1958; Mygind and Winther, 1987).

(iii) Olfactory Theory: by Cloquet (1830) assumed that the sinus cavities in man were lined with olfactory epithelium. The olfactory mucosa in man – with his poor sense of smell – is limited to an area in the roof of the nasal cavity and respiratory epithelium lines the sinuses (Rhys Evans, 1987).

(IV) Thermal Insulation Theory: by Proetz (1953) compared the sinuses to "an air jacket about the nasal fossae closely resembling the water jacket of the combustion engine". This theory was discredited because the air circulation required for this theory is inadequate between the nose and the paranasal sinuses, because of the small ostium (Negus, 1958). Furthermore, species that require the greatest warming of air, for example Polar bears, have complex turbinate structures that are highly vascularised and offer a large surface area for warming.

(V) Lightening Of The Skull: has also been suggested as another role of the paranasal sinuses. According to Skillern (1920) the role of the paranasal sinuses is to lighten the skull, particularly its anterior half in order to reduce the work of the neck muscles. According to Negus (1958) an absence of sinuses would, in itself, lighten the skull.

(VI) Facial Growth Theory: by Proetz (1922) relates the presence of the nasal sinuses to be directly related to the development of the face. Proetz states that we are not to "attribute to these cavities any further functional activity" (Rhys Evans, 1987). According to this theory the sinuses result incidentally and are only unoccupied spaces. Recent literature highlights the importance of craniofacial development and states that the increase in the angle between the forehead and the frontal cranial base is significant in dictating sinus morphology. (Takahashi, 1983; Shea, 1985 and Blaney, 1990)

(VII) Buoyancy Theory: Rhys Evans in 1992 developed a Buoyancy Theory for paranasal sinus function. This theory essentially suggests that the sinuses developed as a result of man being a semi-aquatic animal, in order to allow the head to come upright after diving. In modern man the sinuses are a remnant associated with this function (Rhys Evans, 1992). Evidence supporting this theory would be the presence of ear canal exostoses if sufficient fossil remains of early anthropoid man were found. This would suggest that early man spent much time in the water for hunting rather than for social purposes.

The above arguments do not adequately explain the presence of the paranasal sinuses in the human skull. It is the opinion of this researcher that the human paranasal sinuses may be multi-functional, as aspects of different theories appear to be significant. This is an anatomical and volumetric study whose results aim to be interpreted into forensic medicine by finding a place for the paranasal sinus measurements in human identification and by extrapolating any relevant findings of this cadaver study to clinical medicine. The relevance to forensic medicine is the race and sex differences in the human paranasal sinuses and the relevance to clinical medicine is the understanding of disease and the treatment thereof. Disease of the sinuses occurs regardless of function and the treatment of disease is the basis of surgery in this region. Anatomical form or variation in itself may bear a relationship to how surgery is performed in this region with race and sex anatomical differences becoming significant. This research has been conducted with the underlying premise that irrespective of paranasal sinus function, anatomical, race variations are of paramount importance to surgeons in clinical medicine, and in forensic medicine to forensic investigators, as well as to anatomists, anthropologists and related disiplines.

2.2 FORENSIC MEDICINE , ANTHROPOLOGY, CRANIOLOGY; AREAS OF RELEVANCE TO THIS RESEARCH

An interesting and challenging aspect of forensic medicine is identification, particularly the identification of crania. Forensic pathologists, when identifying skeletal material, initially focus on age, sex and racial grouping. These highly significant determinations are the basis of identification. In order to proceed with techniques such as facial reconstruction, it is necessary to have an accurate as possible determination of age, sex and racial grouping. Therefore, research aimed at enhancing the accuracy of any of these areas is of extreme value to the field of forensic pathology.

Human Biological Variation

Human biological variation is a pivotal anthropological concept relevant to this research as the race and sex differences found in crania of different origins will provide new measurable data that can assist in classification, and in so doing, make a scientific contribution to the field of human forensic identification.

Homo sapiens are a very successful species. They have evolved into many morphologically different populations. Man has long desired to classify these populations. The earliest ancestral studies within anthropology reflect this. Today, determination of ancestry is key in biological profiling and the ability to recognise inherited traits, according to lineage and ancestry, is very important to forensic medicine.

This research, aims, where possible, to avoid the concepts of race and nationality. By race we mean geographic ancestry. The South African Zulu sample is a homogeneous group with a recognisable culture and little racial mixing. The Europeans, in this study, were descendants from Europe and represent a more heterogeneous sample. The historical studies on human variation did involve racial classification, but this study aims to be sensitive to the social connotations and is aware of the 'race debate' in anthropological circles. Whilst it is critical to this study to recognise that morphological and proportional differences exist between populations, it is important to realise that these determinations are critical to make when identifying human remains–often in an advanced state of decomposition - with the sole purpose of accurate identification of a person.

In the 18th-century, studies of human biological variation were based upon descriptions of human populations. Early studies were focused on phenotypic characteristics visible to the eye. Linnaeus (1707–1778) was the first to describe human biological variation by dividing people into one of four classifications: Homo sapiens Europeas, Homo sapiens Americanus, Homo sapiens Asiaticus and Homo sapiens Africanus. Linnaeus's classification lacked anatomical differences and was based on soft tissue, morphology and behaviour (Linnaeus 1759).

Other early researchers such as Blumenbach (1775) and Leclerc, Buffon and Kant, of that era, attributed human biological variation to factors such as climate and nutrition (Hefner, 2007).

Blumenbach classified humans into 5 varieties: Caucasian, Mongolian, Ethiopian, American and Malayan (Blumenbach 1775). Brace (1997) credits Blumenbach (1775), for discovering that persons within a geographical area resemble their ancestors.

Morton's publication, Crania Americana (1839), classifies human into four distinct races based on Blumenbach's research (Morton 1839). Morton's research has been cited in the literature as proof of biologically distinct races (Rushton 1999).

By the 20th century, Boas (1912) challenged the race concept and its usefulness for human variation studies. Boas published a famous study that challenged the prevailing belief that firm genetic rules governed cranial shapes (Holden 2002). Boas took measurements from 13 000 European immigrants and their offspring in New York. The sample comprised 7 race groups. He compared parent–offspring resemblance in immigrants whose children were born in the United States with those whose offspring were born in Europe. Boas wanted to see if living in the New World had an effect on skull shape. (Holden 2002).

By using the Cephalic Index–the ratio of head breadth to head length, Boas found a small yet significant trend. He found that children born in the United States were different from their foreign-born parents. "Jews who had very round heads became more long headed while long headed Italians became more short headed–so that both approached a uniform type in this country". According to Holden (2002), the study is often cited as evidence that humans cannot be pigeonholed into racial categories because their morphology is too malleable (Holden, 2002).

Boas's study became the topic of much controversy in anthropological circles with some authors concluding that he was right whilst others opposed his findings. According to his critics, the divergences in the United States born offspring are negligible and the influence of the environment is insignificant. Today the debate continues with researchers such as Sparks and Jantz from the University of Tennessee upholding the view that the environmental influence is negligible (Holden, 2002) and opposing research as such as Gravlee, from the University of Michigan, reporting that the difference in Boas's two groups of offspring is small but highly significant (Holden, 2002).

In essence, Boas showed that the Cephalic Index is sensitive to environmental influences and therefore does not serve as a marker of racial phylogeny. The opposing view maintains that Boas shows how small that environmental response really is (Holden, 2002).

Hooten (1887–1954) was, at the same time as Boas, attempting to search for a biological distinction of races (Hefner, 2007). Hooten collected non-metric and metric data from varying populations and divided humans into 3 races: White, Negroid and Mongoloid (Hooten, 1926). These 3 races he defined as primary races that could be divided into secondary races. In addition, Hooten was able to define eight morphological types that can be classified into one of the three major races (Hefner, 2007). This list became the Harvard Blanks (Brues1990). The Harvard Blanks is an important list among several non-metric traits for assessing ancestry. Today, lists of nonmetric traits are still used when assessing the ancestry of unidentified remains (Birkby et al, 2008; Gill 1998; Rhine 1990).

Introduction to this Craniological Study; within the context of Human Biological Variation:

In physical anthropology, a science which is concerned inter alia with the origins, evolution and diversity of mankind, the study of the skull occupies a central place. Such investigations depend on comparisons of skeletal size and forms in various populations, in order to suggest patterns of interrelationship or biological affinities existing among populations. Skeletal measurements however, are likely to be affected by environmental factors as well as genetic factors. Moreover, the inheritance of quantitative characters seem to depend on the combined influence of many genes, the individual actions of which are difficult to determine (Tobias 1953, 1960 a, 1960 b) as cited by Wolfowitz (1974).

Other studies have focused on simpler forms of inheritance, such as blood groups. It is noted that genetic changes may produce an evolutionary advantage to the population in a particular area, which will then predominate in that population. Where these changes produce visible changes, such as skin colour, it has brought about the concept of race. However there are other differences such as blood groups that are a result of geography.

There is no evidence for assuming that monogenic traits are better indicators of racial affinity than polygenic traits. Wolfowitz (1974) quotes authors such as Pollitzer (1958) and Mourant (1962) who point out that monogenic factors are more likely to be affected by random fluctuations. According to Bielicki (1962), polygenic traits offer the most reliable basis for determining the effects of hybridisation, and for indicating racial affinities (Wolfowitz 1974).

In Southern Africa:

Tobias (1953, 1960 a, 1960b) advocated a synthesis of these two methods by suggesting that methods of anthropometry and gene frequency analysis should be complementary to each other, and that the degree of biological distance between populations would be indicated most reliably by the analysis of polygenic metrical traits as well as of monogenic and oligogenic traits. According to Wolfowitz (1974), this approach has been used in studies in living groups (Sanghvi 1953, Pollitzer 1958), and in studies on cranial series (Laughlin and Jorgensen 1956, Brothwell 1960).

In the South African crania, it is well known that certain morphological features, which are extremely difficult to measure, are of great value in distinguishing crania of various African race groups. Dart (1924) describes the mons temporosphenoidalis as a characteristic feature of the San bushmen crania. Wells (1929) recognised the frontal eminence as a striking feature of the San (bushmen) cranium. In 1937, Galloway made a systematic study of a number of features in groups of San, South African Negro and "Boskopoid" crania. De Villiers (1968) describes a patent foramen of Huschke as a common feature of the San Bushmen cranium. De Villiers, in 1972, further studies the relationship between Bushmen and South African Negro tribal groups (Wolfowitz 1974).

Nonmetric and Metric Methods of Determining Ancestry:

In forensics, the establishment of race is a difficult part of skeletal identification and most of the features which determine race are associated with the skull and face (Adelson, 1974), Traditionally, racial identification of a cranium involves a comparative analysis of: the shape of the cranium; the ramus of the mandible; the chin; the nasal aperture; the nasal *bones; the cranial sutures; the palatal shape; the degree of prognathism; the zygomaxillary suture; the zygomas and the dentition- particularly the incisors.*

The nonmetric method of assessing ancestry involves the above detailed comparisons between differing race and race groups.

Brues (1990) found the nasal region to be useful in ancestral identification and classifying crania. Brues argued that the nasal contour across the nasal root differs in morphology between Blacks, Whites and Asians with Blacks having a nasal root the shape of a Quonset hut; Whites having steeped nasals and Asians having tented nasals (Brues 1990).

Brooks et al (1990) found differences in prognathism of the maxillary alveolus region among ancestral groups. Hinkes (1990) did studies on incisors and determined that eighty five to ninety percent of Asians have a shovel shaped incisor trait that Whites do not possess (Hinkes 1990). Rhine (1990) compiled lists of nonmetrical traits for American Caucasoid, Southwestern Mongoloid and American Black populations.

Nonmetric methods are limited predominantly because of the difficulty in defining the non-metric differences seen between the population groups. The meaning of the terms such as "low rounded" may mean different things for different researchers. Furthermore the terms are subjective. Studies are limited to certain geographical areas with most of the research being done in the USA and little being done in Africa and Australia and some other parts of the world. Sample size is often small; where crania are used the collections are limited and some are damaged. This limits the establishment of ancestry in crania of unknown origins.

These limitations established the need for metrical methods.

Metric evaluations are based on metric measurements of standardized cranial landmarks from the standards set at the Frankfurter Verstandigung in 1882.

Authors such as Giles and Elliot (1962) have focused on metrical methods of forensic race and sex identification, using discriminant analysis formulae. Their method was created using the Terry collection as well as prehistoric Native American crania from Indian Knoll. Several authors have deemed this method to be inaccurate (Ayers et al, 1990; Snow et al, 1979). This was the first study to use discriminant functions to assign crania into different racial categories.

In 1990, Gill and Gilbert created a metrical method of distinguishing between American Blacks and Whites by using metrical measurements of the mid-face.

The FORDISC 3.0 computer program (Jantz and Ousley 2005), a popular choice used today, also uses discriminant function analysis to classify cranial measurements into population groups. Its database comprises measurements of 28 populations. Whilst a current technique, it has been heavily criticized for being subject to user manipulation and for misclassifying skulls (Belcher et al, 2002; Leathers et al, 2002;Williams et al, 2005).

Sex identification:

Establishing sex from a skull is mostly based on morphological characteristics. Earliest descriptions date back to the 18th century. Opinions have been divided on how to distinguish between male and female crania in the most reliable way. Prokop and Gohler (1976) state that it is more difficult to determine the sex of an individual if the skull alone is available (Graw 2000). Holland (1986) and Bass (1987) state that the skull comes second to the pelvis when differentiating sex from the skeleton. The pelvis and cranium are excellent sites for determining the sex of a skeleton. Because the pelvis is often damaged, the cranium is often used for sexing as it is better preserved. A long - standing debate also exists regarding whether morphological (visual) or morphometric traits are more effective and determining sex (Stewart 1954). Morphological trait assessment is subjective but metric trait assessment is affected by inexperience.

When assessing sex, seventeen primary morphological characteristics are used. These characteristics are based on early researchers work and numerous studies have looked at various aspects of these characteristics. Graw (2001) retested these characteristics in German crania and found that only five traits were considered sufficiently reliable for sex differentiation (70-80%) i.e. glabella, arcus superciliaris, processus mastoideus, crista supramastoidea and mandibula (overall impression) (Graw 2001).

When determining the sex of a skeleton from the cranium, in general terms the following features are examined. The external occipital protuberance and the mastoid process are more pronounced in men than in women. The male jaw is closer to the width of the cranium than the female jaw. The male jaw is more angular than the females and the teeth are larger. Finally the male brow is thicker and more pronounced in males than in females. Together these traits help establish sex (Graw 2001).

Often with decomposition, the skull is the last remaining part of the skeleton available to analyse. The skull itself is fairly resistant to decomposition and so becomes important to find methods to correctly judge race group and sex from it.

The classification of a cranium according to race and sex is of great value in Identification. A potentially serious error for example, would be that of imposing male features on a female cranium or Negroid features on a Caucasian cranium. The forensic pathologist or forensic physical anthropologist dealing with skeletal material can be highly accurate in a complete intact skeleton when assigning race and sex. Sometimes the situation is more challenging and a forensic pathologist may be required to identify a cranium of unknown origin. Assigning race group (geographic ancestry) and establishing sex (biological sex), are of paramount importance; as together with the establishment of age, they form the basis of correct identification.

And so there exists a need to add new metrical research that will aid race and sex determination to the field of forensic science. Of interest is that this is a study based in Africa, unlike the many based in the US and other first world countries. The Dart collection comprises of a large number of excellently preserved crania. The methodology of helical computed technology (CT) is ideal for taking accurate measurements of the crania.

The question is:

Will an analysis of the sinuses, their volumes, shape and dimensions in dried crania of different race and sex groups, establish a new approach of assessing race and sex in unidentified skeletal remains?

2.3 ANATOMICAL LITERATURE RELEVANT TO THIS STUDY ANATOMY OF THE NOSE AND PARANASAL SINUSES

2.3.1 Introduction

This chapter reviews the anatomy relevant to this study. As this is an anatomical cadaver study and variations in the volumes and measurements of the maxillary, ethmoid, frontal and sphenoid sinuses are investigated; it is imperative to review the relevant anatomy for the purpose of a comprehensive understanding of the context of this study.

The paranasal sinuses are air filled cavities. Their volumes are directly related to their shape, which is the result of the apposition of many bones. To understand this fully it is essential to understand how these bones form and fuse to produce the final structure. The structure of the paranasal sinuses is likely to bear a relationship to their function even though the functional significance of the paranasal sinuses is still to be clarified. A working knowledge of the relevant embryology and anatomy is an essential part of this study in order to optimally interpret the results of this research. *Additionally, in forensic medicine, there is true value in making discoveries that may have a direct bearing on clinical treatment and surgical significance. Such examples could be the modification of surgical instrumentation for sinus procedures or information gleaned for dental implantology in maxillofacial surgery. The aim of this research is to identify variations for human forensic identification, but the additional anatomical variations that have clinical significance will be discussed and noted.*

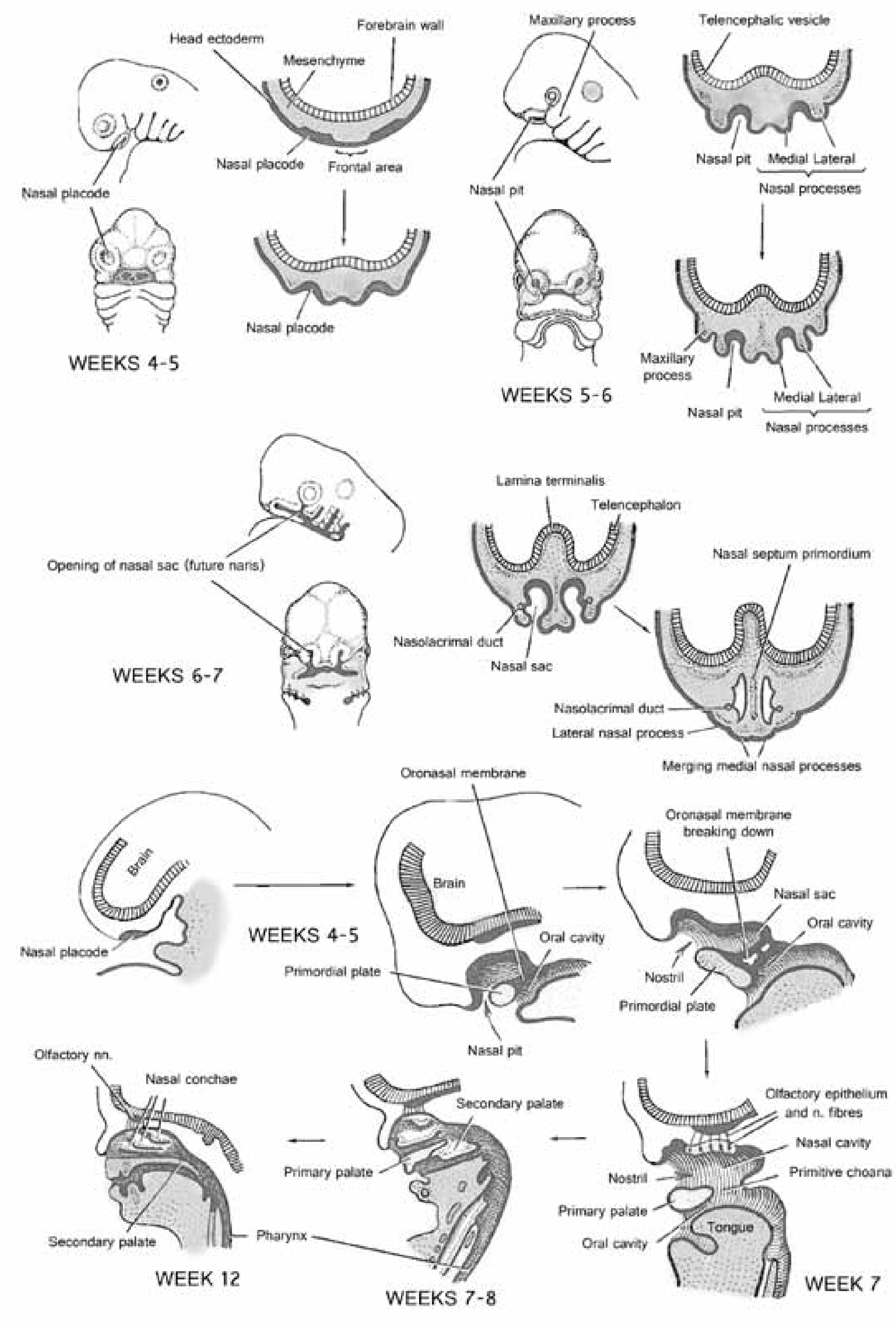
2.3.2 Embryology

2.3.2.1 Early Embryological Development

Early embryologic development in relation to the anatomy of the nose and paranasal sinuses begins with structural changes in the original yolk sac vesicle. Of importance is the rotation of the cephalic end of the embryonic disc with the formation of the embryo head.

In the fourth intrauterine week the olfactory placode sinks in to form the olfactory pit which lies between the growing mesoderm of the medial and lateral nasal folds of the frontonasal process (Lund, 1997). By the fifth intrauterine week this deepens to form the nasal sac.

FIGURE 2.1 EARLY EMBRYOLOGICAL DEVELOPMENT OF THE HUMAN NOSE AND PARANASAL SINUS REGION



Source Reference: LifeMap Discovery. Embryonic Development & Stem Cell Compendium. Chapter 57. Free for Academic Non profit institutions.

Primitive nasal cavities are formed from the fusion of the maxillary process of the first branchial arch (growing anteriorly and medially) with the medial nasal folds and the frontonasal process. The bucconasal membrane initially separates the primitive nasal cavity and the mouth. As the nasal sacs extend posteriorly this breaks down to form the primitive choanae then "the floor anterior to the choana forms from the mesenchymal extensions of the medial nasal folds to produce the premaxilla and ultimately the upper lip and medial crus of the lower lateral cartilages" (Lund, 1997). The mandibular process gives rise to the maxillary process, which joins the lateral nasal fold around the naso-maxillary groove. The nasolacrimal duct forms in this region. The nasal bones, upper lateral cartilages and lateral crus of the lower lateral cartilages are also formed from the lateral nasal folds.

2.3.2.2 Embryological Development Of The Paranasal Bones And Sinuses Relevant To This Study

A. THE MAXILLA

In the sixth and seventh week of embryological development the maxilla arises from five ossification centres, which fuse in the fourth foetal month and form the alveolar, palatine, zygomatic and frontal processes and the floor of the orbit. The premaxilla forms in the medial floor of the pyriform aperture. The anterior nasal spine is formed from the premaxilla and then fuses with the septal cartilage superiorly and the vomeronasal cartilages laterally (Lund, 1997).

B. THE ETHMOID BONE

"The ethmoid bone ossifies in the cartilaginous nasal capsule from three centres, one for each labyrinth and one for the perpendicular plate" (Lund, 1997). By the fifth foetal month the centres for the labyrinth are present – by birth they are partially ossified. By the end of the first year after birth the perpendicular plate and crista galli have developed from one centre and at the beginning of the second year of life they fuse with the labyrinths. The cribriform plate is formed from the abovementioned centre and the centre for the labyrinth.

C. THE FRONTAL BONE

In the eighth intrauterine week the frontal bone ossifies in membrane from two centres; one present in each supercillary ridge. The bone at birth is comprised of two halves, which are separated by a frontal suture. Fusion between the bones occurs at two years of age and the process is completed by the eighth year of life in most cases.

D. THE SPHENOID BONE

Two parts make up the sphenoid: The presphenoidal portion and the postsphenoidal part. The former comprises the portion anterior to the tuberculum sellae, continuous with the lesser wings and made up of six separate ossification centres. The post sphenoidal part is comprised of the sella turcica and dorsum sellae associated with the greater wings and pterygoid process developed from eight centres. At approximately the eighth intrauterine month, the pre and post sphenoidal parts fuse. By birth the sphenoid bone consists of three parts: a central portion which comprises of the body and lesser wings; and two lateral parts each comprised of a greater and lesser wing and pterygoid process, which fuse at a year after birth. (Lund, 1997).

E. THE TURBINATE BONES

From the sixth foetal week elevations appear on the lateral nasal wall. The elevations will develop to form the turbinates. The maxilloturbinal forms the inferior turbinate whilst the middle superior and supreme turbinates arise from the ethmoturbinal system. It must be noted that the inferior turbinate is not part of the maxillary sinus or maxillary bone.

F. THE MAXILLARY SINUS

At approximately 12 foetal weeks the maxillary sinus arises as a result of prolongation of the ethmoid infundibulum. At birth the maxillary cavity measures 7X4X4mm. (Ritter, 1973). It is located between the orbit and the dentition. The maxillary sinus grows with the growth of the middle third of the face and its growth is influenced by the eruption of dentition. As the teeth erupt downwards, the maxillary sinus expands inferiorly. The maxillary sinus generally grows during childhood with its maximum size achieved around age 15. On occasions there may be hypoplasia of the sinus or only one maxillary sinus may develop (De Weese and Saunders, 1994).

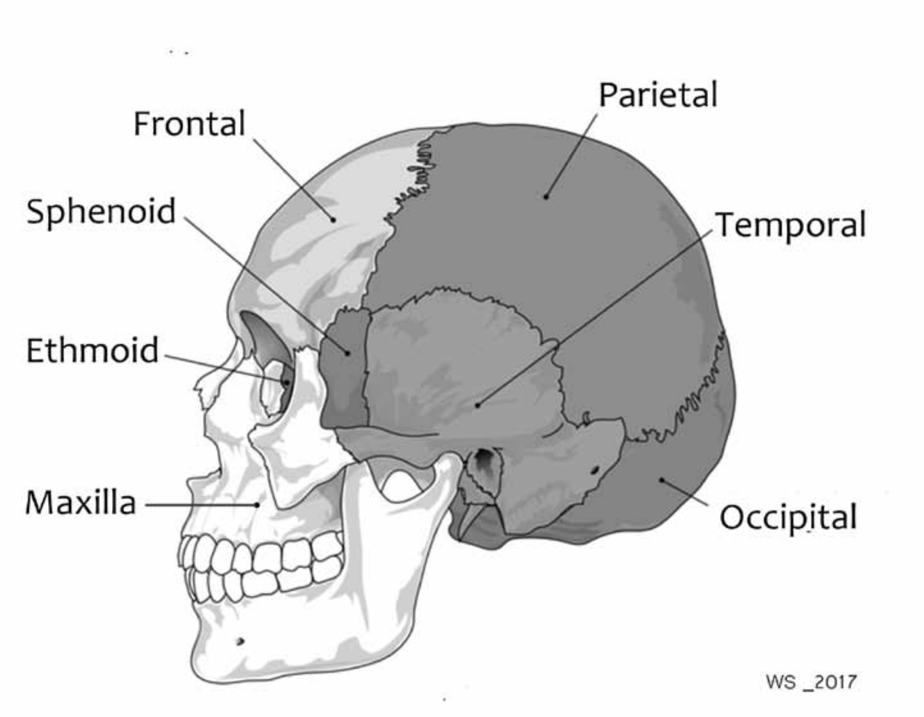
G. THE ETHMOID SINUS

Early development of the ethmoid sinus occurs around the fifth foetal month when ectodermal invaginations develop on the lateral nasal wall and grow laterally into the ethmoid bone (Rhys Evans, 1987). By birth a few ethmoid cells are present. These continue to grow until late puberty approximately until the head stops growing.

H. THE SPHENOID SINUS

By the third intrauterine month the sphenoid sinus is present as an invagination from the sphenoidal recess and a small cavity is present at birth measuring approximately

FIGURE 2.2   9 CRANIAL BONES



2 x 2 x 1.5mm. This cavity reaches full size in adolescence and may expand in old age (Lund, 1997).

I. THE FRONTAL SINUS

Embryologically the frontal sinus may be regarded as an anterior ethmoidal cell. The frontal sinus exhibits the most variation in shape and size (Lund, 1997). In the third intrauterine month a small frontal recess is recognizable. It is after birth that upward expansion occurs. Much anatomical variation is exhibited in the frontal recess and sinus: septation, drainage channels and diverticulae may be present. The frontal recess may have anterior ethmoid cells encroaching upon it. This sinus is the last to complete its growth, in early adulthood. It also is known to undergo pneumatisation from approximately 12 years of age.

2.3.3 Anatomy

2.3.3.1 The Maxillary Bone And Sinuses- Osteology

The inherent shape of the midface is determined by the maxilla. This bone is the second largest facial bone. It is pyramidal in shape and the body contains the maxillary sinus, which is the largest sinus of the paranasal sinuses. The maxillary bone contains four processes: the alveolar; frontal; palatine and zygomatic processes. It articulates with the following bones:

i. The nasal bones superiorly,

ii. The inferior concha medially,

iii. The palatine posteroinferiorly,

iv. The ethmoid posterosuperiorly,

v. The lacrimal superomedially,

vi. The zygoma superolaterally,

vii. The frontal bone superiorly,

viii. The opposite maxilla medially below the nasal cavity forming the floor of the nose.

Superior to the maxilla lies the infraorbital canal through which the infraorbital artery and nerve travel. The orbit is also situated superiorly in relation to the maxilla. Inferiorly lie the palate and upper dentition. Posteriorly is the pterygopalatine fossa and posteriorly and laterally the infratemporal fossae is situated. Exteriorly lie the cheek and facial muscles (Lund, 1997).

2.3.3.2 The Maxillary Sinus

The maxillary sinus, the largest of the paranasal sinuses has the shape of a quadrilateral pyramid on its side. It is located within the maxilla on each side of the nasal cavity. The apex of the pyramid lies laterally extending into the zygomatic process of the maxilla or into the zygomatic bone itself"(Rhys Evans, 1987). The base of the pyramid forms the lateral nasal wall.

The bone of the medial wall is composed of the "medial wall of the maxilla, the maxillary process of the interior concha, the perpendicular plate of the palatine bone, the uncinate process of the ethmoid bone and the descending portion of the lacrimal bone" (Rhys Evans, 1987). The floor of the sinus comprises the alveolar and palatine processes of the maxilla. The size of the sinus is highly variable but according to Rhys Evans (1987) the dimensions in the adult skull are approximately 33mm in height, 23mm in width and 34mm in anterior-posterior depth. Furthermore, Rhys Evans gives a volumetric range of 14.72ml to 30ml. (Rhys Evans, 1987).

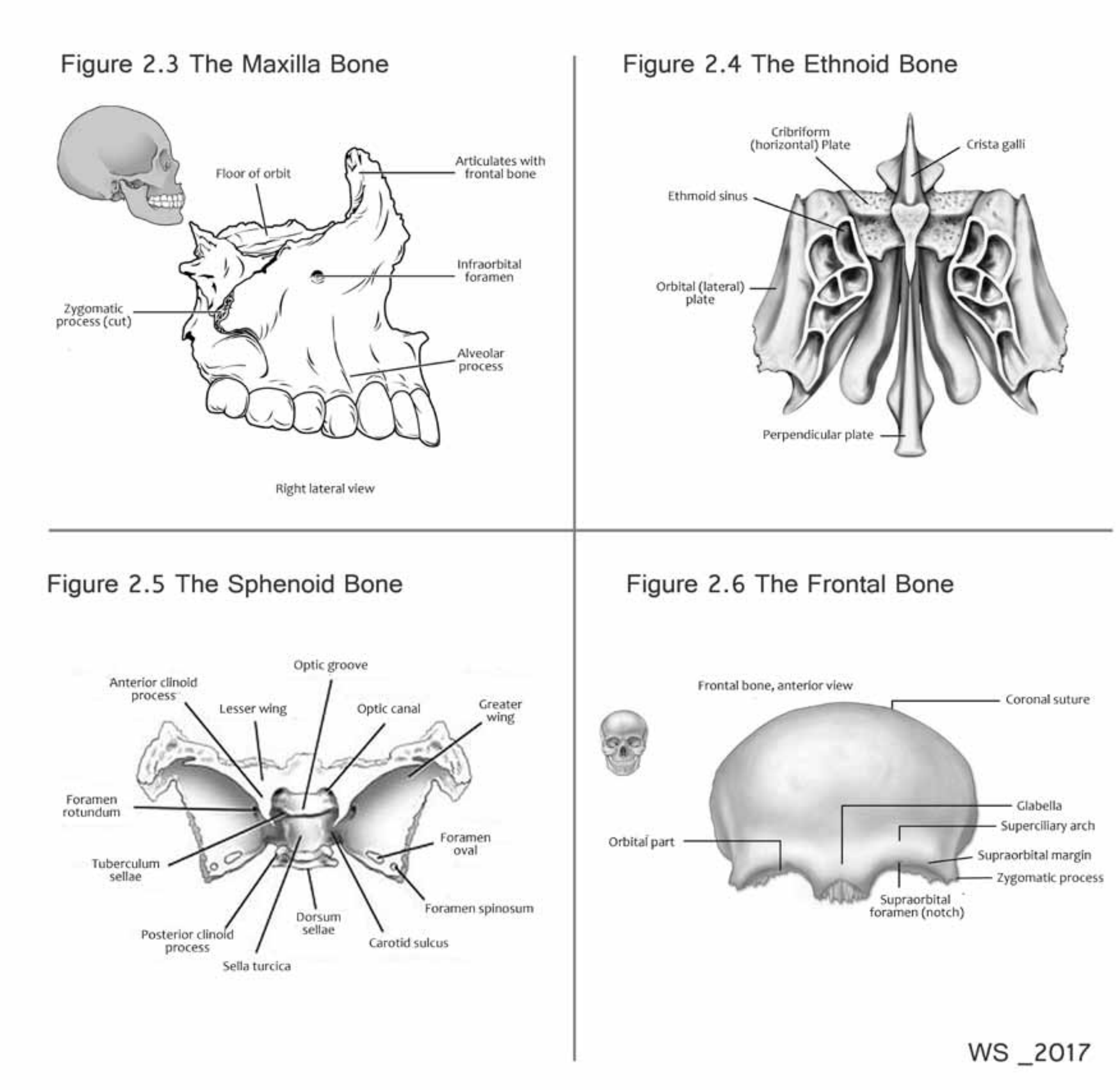
The inferior floor of the sinus is thicker than the rest of the sinus and may be influenced by dentition. *However, the findings of Uchida et al (1998) and Ariji et al (1984) support the view that dentition does not influence the volumes of the maxillary sinus in the adult which is the relevant aspect for this particular research.* The sinus develops to varying degrees into the alveolar process according to Schaeffer (1910). The three molar teeth are directly related to the floor of the sinus and related to pre-molars less frequently. The ostium of the maxillary sinus is located superiorly on the sinus's antero-medial wall and opens via the ethmoidal infundibulum in the middle meatus. The orbital floor is formed predominantly from the roof of the maxillary sinus. Between the roof of the maxillary sinus and the floor of the orbit lies the infraorbital canal through which runs the infraorbital artery and nerve. The maxillary sinus itself is lined by ciliated columnar epithelium, which is directly related to its physiological function. The facial, maxillary, infraorbital and greater palatine arteries and veins supply and drain the maxilla. As this study is performed on dry crania this aspect of the anatomy and physiology will not be detailed further.

FIGURE 2.3 THE MAXILLA BONE

FIGURE 2.4 THE ETHMOID BONE

FIGURE 2.5 THE SPHENOID BONE

FIGURE 2.6 THE FRONTAL BONE



2.3.3.3 Physiology Of The Maxillary Sinus

Normal physiological function of the paranasal sinuses is dependent on drainage and ventilation. This study is concerned with anatomical variation and volumetric differences of the sinuses. The physiology of the sinuses is relevant because surgery is directed at restoring the normal function of the sinuses.

The maxillary sinus is lined by ciliated, columnar epithelium containing a high number of goblet cells. Messerklinger, in his studies on cadaver heads, identified the pathways of secretion transport in the paranasal sinuses (Stammberger, 1991). In the maxillary sinus mucus transport begins in the floor of the sinus. The mucus is transported along the anterior, lateral, posterior and medial walls and along the roof of the sinus (Stammberger, 1991). The natural ostium of the maxillary sinus is the point where all the secretion routes converge. The secretions subsequently pass into the ethmoidal infundibulum and then into the middle meatus, via the hiatus semilunaris. *All current surgery is directed at opening the natural ostium to allow ventilation and drainage of the sinus to occur in a normal manner. The volumetric aspect of the study may give surgeons information about ease of anatomical access.* Blood supply to the maxillary sinus is via branches of the facial, infraorbital, maxillary and greater palatine arteries and veins.

Nerve supply is from the maxillary division of the trigeminal nerve, which supplies sensation via the infraorbital, superior alveolar and greater palatine nerves (Lund, 1997). The anterior superior alveolar nerve supplies the anterior wall of the maxillary sinus. The posterior superior alveolar nerves supply the adjacent mucosa and molar teeth. The middle superior alveolar nerve supplies the lateral wall of the sinus and the greater palatine nerve supplies the posteriomedial wall of the sinus, whilst branches of the infraorbital nerve supply the roof. Lymphatic drainage is into the pterygopalatine fossa and submandibular nodes.

2.3.3.4 The Ethmoid Bone And Sinuses.

This bone is comprised of the following parts:

a. Two ethmoidal labyrinths attached to a perpendicular plate.

b. Perpendicular plate forming superior portion of nasal septum

c. Cribriform plate

d. The crista galli- a superior midline extension of the perpendicular plate of the ethmoid. The bone is cruciate in form and exhibits anatomical variation between individuals (Lund, 1997).

The perpendicular plate articulates with the nasal spine of the frontal bone and nasal bones. It also articulates posteriorly with the sphenoid and the vomer.

The crista exhibits variations in length with a mean length of 21.6 mm (Lund, 1997). The crista may be pneumatised to varying degrees although this is rare.

The nasal cavity and the anterior cranial cavity are separated by the presence of the cribriform plates.

The ethmoid sinuses essentially consist of a number of air cells divided into anterior and posterior air cells. The number of air cells varies between individuals. The middle turbinate is a shelf of bone protruding into the nasal cavity which attaches anteriorly to the agger nasi and to the nasal process of the maxilla and posteriorly, it attaches horizontally to the inferior portion of the lamina papyracea. In-between is an oblique plate of bone attached to the lamina papyracea called the basal lamella, which is part of the middle turbinate and serves to divide the ethmoidal labyrinth into the anterior and posterior ethmoid cells.

The most posterior ethmoid cell may extend laterally to the sphenoid and be closely applied to the optic nerve and is referred to as an Onodi cell. The optic nerve is particularly vulnerable to injury in these cells. There is noted race variation in the incidence with which Onodi cells are found (Lund, 1997) Haller cells are described when ethmoidal cells pneumatise the floor of the orbit. *This study will take the presence of these two types of cells into account and assess any race or sex variation that may be present.*

The bony roof of the ethmoid is provided primarily by the frontal bone (Stammberger, 1991). The ethmoid bone is open superiorly over its anterior two thirds. The "roof" for these open cells and ethmoidal clefts is provided by the frontal bone. *Because the roof of the ethmoid exhibits much anatomical variation, it is essential that the surgeon have a thorough knowledge of the anatomy of the area prior to performing surgery.*

2.3.3.5 Related Anatomy Of The Ethmoid Region

A. THE AGGAR NASI

The aggar nasi is an anterior bulge on the lateral wall just anterior to the attachment of the middle turbinate. Anatomical variations exist in the amount of pneumatisation although is only occasionally pneumatised. In animals with a snout, the agger nasi forms a separate turbinate system.

B. HIATUS SEMILUNARIS

The hiatus semilunaris can be described as the "foyer"; the space from which leads the path to the frontal, maxillary and ethmoid sinuses. The space lies between the posterior edge of the uncinate process and the anterior surface of the ethmoidal bulla.

C. ETHMOIDAL INFUNDIBULUM

This area is the key to endoscopic sinus surgery and its anatomy is of keen interest to endoscopic sinus surgeons primarily because obstruction at this level is the main cause of sinus disease.

The ethmoidal infundibulum can be reached from the middle meatus by going through the hiatus semilunaris. It is funnel-like and connects the natural ostium of the maxillary sinus to the middle meatus, via the hiatus semilunaris. The natural ostium of the maxillary sinus lies in the floor of the ethmoidal infundibulum. (Lund, 1997). Its landmarks are: medial: uncinate process and hiatus semilunaris, lateral: lamina papyracea, anterior: an acute angled blind recess where the uncinate process meets the lamina papyracea, posterior: anterior face of the ethmoidal bulla, superior: varies according to uncinate process attachment.

D. THE FRONTAL RECESS

This is a region into which the frontal sinus drains via the ostium, into the middle meatus. It is located anterosuperiorly in the middle meatus. "Depending on the position of the uncinate process, the frontal recess opens into the middle meatus, medial to the uncinate process and between this structure and the middle turbinate, or directly into the ethmoidal infundibulum" (Stammberger, 1991).

E. THE ETHMOIDAL BULLA

This is the largest air cell in the anterior ethmoid. It may be poorly aerated or completely unpneumatised in 8% of patients (Stammberger, 1991). The bulla has the following orientation:

(i) Anteriorly the bulla forms the "posterior margin of the hiatus semilunaris and ethmoidal infundibulum" (Lund, 1997).

(ii) Superiorly the bulla may form the posterior wall of the frontal recess by reaching the roof of the ethmoids.

(iii) Posteriorly, it can fuse with the basal lamella of the middle turbinate and its anterior aspect forms the posterior margin of the hiatus semilunaris and the ethmoidal infundibulum.

The lateral sinus is a cleft that may be found between the posterior wall of the bulla and the basal lamella of the middle turbinate (Lund, 1997).

Anatomical variations are plentiful in this region and authors such as Zinreich, Kennedy and Gayler (1988) have related anatomical variations and sinus infection. This study will closely examine race and sex variations in the context of forensic human identification and where relevant, clinical applications of any variation found.

2.3.3.6 Physiology Of The Ethmoid Sinuses

Thin ciliated columnar respiratory epithelium lines the ethmoidal sinuses. The density of goblet cells is lower than that found in the maxillary sinus with a mean of 6500 / mm2 (Lund, 1997). The mucosa of the ethmoids has several tubuloalveolar seromucinous glands within it. Mucus transport is through the infundibulum into the nasal cavity beneath the middle turbinate and then posteriorly to the postnasal space. Blood supply to the ethmoid sinuses is via the anterior and posterior ethmoidal arteries and sphenopalatine arteries. The ethmoidal arteries arise from the ophthalmic artery, which is a branch of the anterior cerebral branch of the internal carotid. The anterior ethmoidal artery supplies the anterior ethmoid and frontal sinus. This artery passes through the anterior ethmoidal canal, located on the medial wall of the orbit, it then traverses the roof of the ethmoid and passes through the vertical attachment of the middle turbinate and supplies the upper nasal septum and lateral nasal wall. The posterior ethmoidal artery traverses a canal in the medial wall of the orbit to supply the posterior ethmoidal air cells, the posterior part of the nasal septum and the posterior part of the lateral nasal wall and it anastomoses with the sphenopalatine artery.

Of significance to endoscopic sinus surgeons is the relationship of the anterior ethmoidal artery to the roof of the ethmoid and to the middle turbinate where it can be easily damaged. The ethmoidal sinuses are innervated by the anterior and posterior ethmoidal nerves and orbital branches of the pterygopalatine ganglion. Lymphatic drainage is to the submandibular nodes and retropharyngeal nodes in the neck.

2.3.3.7 The Sphenoid Bone And Sinuses-Osteology

The sphenoid bone is the largest bone in the skull base dividing the anterior from the middle cranial fossa. The sphenoid bone has a body, two wings- the greater and lesser wings and two inferior plates- the medial and lateral pterygoid plates. The jugum on the anterior surface of the body of the sphenoid articulates with the cribriform plate. The body of the sphenoid sinus is pneumatised to a variable extent (Lund 1997). The anterior face of the body bears a grest, which articulates with the perpendicular plate of the ethmoid. On either side of the crest lie the ostia of the sinuses and these are partially overlapped by the superior turbinate and form the sphenoethmoidal recess. The sinus cavities are variable in size and shape and pneumatisation can be extensive. There are four general forms of pneumatisation:

i. Conchal pneumatisation: minimal pneumatisation.

ii. Presellar: pneumatisation extends to the anterior wall of the pituitary fossa

iii. Sellar: pneumatisation extends beneath the pituitary fossa.

iv. Mixed: variable pneumatisation where one side differs from the other.

The sphenoid sinuses are divided by a septum, which is often paramedian but is variable and sometimes incomplete. The inferior surface of the body of the sphenoid has the rostrum, which articulates with the vomer. The greater wings contribute to the middle cranial fossa and to the lateral orbital wall. The superior orbital fissure separates it from the lesser wing on each side and the inferior border contributes to the inferior orbital fissure (Lund, 1997).

The sphenoid bone contains the foramen rotundum through which the maxillary nerve runs, the foramen ovale through which the mandibular nerve, the accessory meningeal artery and sometimes the lesser petrosal nerve travel and the foramen spinosum through which the middle meningeal artery and a meningeal branch of the mandibular nerve pass.

A paired structure located predominantly in the sphenoid bone. Asymmetry in size and shape is most frequently present. The walls of the sinus are irregular. Bony septae partially separate recesses, producing incomplete compartmentalisation of the sinus. There may be dehiscences in the thin bony sinus wall, especially laterally and superiorly. Such dehiscences may result in direct contacts between the sinus mucosa and the overlying dura.

The sphenoid sinus is surrounded by several important anatomic structures. Superior to the sinus lie the cerebral hypophysis, olfactory tract, frontal lobes of the brain, and an often-extensive intercavernous venous network. Anterosuperiorly, the optic chiasm is present. Anteriorly, the anterior margin of the sphenoid bone forms a small segment of the posterior orbital wall. Inferiorly, the nasopharynx is present, as are the blood vessels and the nerve of the pterygoid canal, which run anteroposteriorly immediately below the sinus floor. These structures may be surrounded completely by the bony wall of the pterygoid canal, or they may lie directly underneath the mucosa of the sinus floor.

Posteriorly, a thick, bony wall separates the sinus from the basilar artery and the pons. Anteriorly, an incomplete bony wall separates the sinus mucosa from the nasal mucosa and from the posterior ethmoid sinuses. If the sphenoid sinus is larger, it may extend over the pterygopalatine fossa with its contents, and it may be located directly posterior to the maxillary sinus. Laterally, a thin, bony wall with occasional dehiscences separates the sphenoid sinus from Meckels's cave, the cavernous sinus, and the internal carotid artery; and, along the lower border of the sinus, the maxillary division of the trigeminal nerve.

The ostium of the sphenoid sinus is located high on the anterior sinus wall approximately 1/3 to 1⁄2 up the face of the sinus.

It is crucial to this study to differentiate posterior ethmoidal air cells from the sphenoid sinus and special care will be taken to successfully delineate the two regions.

2.3.3.8 Physiology Of The Sphenoid Sinuses

The sphenoid sinuses are lined with ciliated columnar epithelium, which contains goblet cells and seromucinous glands. The sinus drains into the posterior most portion of the sphenoethmoid recess, above the level of the superior turbinate. Blood supply is from the posterior ethmoidal vessels and nerves. Additional supply is from the orbital branches of the pterygopalatine ganglion. Lymphatic drainage is to the retropharyngeal nodes.

2.3.3.9 The Frontal Bone And Sinuses.

The frontal bone is pneumatised to a varying degree between individuals. The frontal bone forms the forehead and orbital roof and the roof of the ethmoidal sinuses.

The frontal sinus develops from one of the anterior ethmoidal cells but does not start to pneumatise until the first or second year of life (De Weese and Saunders, 1994).

The frontal sinus is only significant after approximately age 9. It is the last sinus to complete its growth in early adulthood *and its configuration is highly variable.*

2.3.3.10 Physiology Of The Frontal Sinuses

The frontal sinus is lined with ciliated columnar epithelium with mucus secreting goblet cells. Drainage is inferiorly via the nasofrontal duct into the frontal recess, which is situated in the anterior part of the hiatus semilunaris in the middle meatus.

The arterial supply is from the ophthalmic artery, which is a branch of the anterior cerebral artery. Branches of the ophthalmic artery feeding the frontal sinus are the anterior ethmoidal artery interiorly and the supraorbital and supratrochlear arteries externally. The venous drainage is intracranial to the superior sagittal sinus, which ends blindly at the foramen caecum at the crista galli. Drainage also via the orbital veins to the cavernous sinus. Nerve supply is derived from the supraorbital nerve. Lymphatics drain to the submandibular gland. *It is extremely difficult to differentiate posterior wall of frontal sinus from anterior fronto-ethmoidal air cells and special care will be taken in this study to delineate correctly.*

2.4 RELATED ANATOMY

2.4.1 Nasal Cavity

The nasal cavity is of relevance to this study because race variations in external anatomical structure are apparent and it is continuous with the paranasal sinuses, nasolacrimal duct and nasopharynx.

A. NASAL SEPTUM

The nasal septum divides the nasal cavity in two. Each side has a lateral and medial wall (septum), a floor and a roof. The septum is made of the vomer, the perpendicular plate of the ethmoid and the quadrilateral cartilage, the crest of the maxilla and the crest of the palatine bone (Lund, 1997). The floor comprises in the anterior two thirds of the palatine process of the maxilla and the posterior third by the horizontal process of the palatine bone. The cribriform plate of the ethmoid bone forms the roof.

B. THE LATERAL NASAL WALL

The lateral nasal wall of the nose comprises of the maxilla, interior turbinate, and the ethmoid labyrinth with its middle and superior turbinate. There are three meatii: an inferior, middle and a superior meatus.

C. INFERIOR MEATUS

This is the largest meatus. It is that part of the lateral wall of the nose infero-lateral to the inferior turbinate. In adults the size ranges from 1.6 to 2.3cm (mean 1.9cm) at 1.6cm along the bony lateral wall (Lund, 1988). The nasolacrimal duct opens into the anterior end of the inferior meatus.

D. INFERIOR TURBINATE

The inferior turbinate is composed of a separate bone, the inferior concha. This is unlike the other turbinates, which are part of the ethmoid bone. Its surface is irregular and grooved by vascular channels to which the mucoperiosteum is attached (Lund, 1997). The inferior concha has a maxillary process, which articulates with the inferior margin of the maxillary hiatus. "It also articulates with the ethmoid, palatine and lacrimal bones, completing the medial wall of the nasolacrimal duct" (Lund, 1997)

E. MIDDLE MEATUS

The portion of the lateral nasal wall, which lies lateral to the middle turbinate. The middle meatus contains drainage sites of the maxillary, frontal and anterior ethmoid sinuses. The ethmoidal bulla bulges into the meatus from the lateral nasal wall. The infundibulum is a groove that lies anterior to the ethmoidal bulla, and follows the curve of the bulla anteriorly to posteriorly. "The ethmoidal infundibulum is a three dimensional funnel connecting the natural ostium of the maxillary sinus to the middle meatus via the hiatus semilunaris" (Lund, 1997). The nasofrontal duct drains into this area. The maxillary sinus drains into the posterior and lower part of the infundibulum. The anterior ethmoid cells drain anteriorly and superiorly into the middle meatus. The maxillary hiatus can be seen in a disarticulated maxillary bone as a large opening in the medial wall of the maxillary bone. In the articulated skull however, it is filled in:

i. Inferiorly by the maxillary process of the inferior turbinates,

ii. Posteriorly by the perpendicular plate of the palatine bones,

iii. Anterosuperiorly by a small portion of the lacrimal bone and

iv. Superiorly by the uncinate process of the ethmoid bone and ethmoidal bulla. In life the mucus membrane and the connective tissue fill in the maxillary hiatus, forming anterior and posterior fontanelles that form the membranous portion of the meatus. This is where accessory ostia are formed. These are holes that occur posterior to the normal opening of the middle meatus and their number and size vary in individuals.

F. THE UNCINATE PROCESS

The uncinate process is a thin bone that extends from an anterosuperior position posteroinferiorly. It lies parallel to the anterior surface of the ethmoidal bulla. It is attached anteriorly to the maxillary hiatus and superiorly in variable ways:

i. Laterally to the lamina papyracea

ii. Superiorly to the skull base and

iii. It may fuse with the insertion of the middle turbinate

There are known anatomical variations present in the structure and positioning of the uncinate process. Therefore, anatomical studies such as this could identify variations.

CHAPTER 3: MATERIALS AND METHODS

COMPUTED TOMOGRAPHY OF THE CRANIA

3.1 MATERIALS

3.1.1 Introduction

This study was performed by scanning the paranasal sinuses of 53 crania that are part of the Raymond Dart collection, which is housed in the Department of Anatomy at the University of the Witwatersrand in Johannesburg, South Africa. Raymond A. Dart began the collection in 1923 and the skeletons have all been catalogued. Race, tribe, sex and stated age are known for each skeleton.

The selection of CT apparatus and methodology are described and discussed with reference to historical methodology. The methods of measurement of the maxillary, ethmoid, sphenoid and frontal sinuses are detailed. Statistical analysis of the measurements of the crania and sinuses are described. An analysis of the maxillary sinus was undertaken first as it visibly showed much variation between the race and sex groups. The maxillary sinus leant itself to the creation of a three-dimensional silicone model. The ethmoid, sphenoid and frontal sinus analysis followed. An additional uncatalogued cranium was also scanned. This cranium was available for destruction and so it was possible to make a three dimensional silicone model of the maxillary sinus from this cranium.

Additional volumes and measurements of paranasal sinuses were later analysed from CT scans of live patients. The scan data was anonymised and paranasal sinus measurements in terms of race and sex were analysed, to look for possible classifications that are applicable to human forensic identification or anatomical variation that may have direct clinical implications for surgery in this region.

3.1.2 The Choice Of Helical Multislice Computed Tomography

Helical multislice computed tomography was the most desirable method available to scan the volumes of the sinuses in this research project. It was selected to investigate sinus volume because it is the most advanced radiographic method chosen by current researchers and is so reflected in the literature. Helical Computed Tomography, although an expensive technique, is a very accurate method available to measure sinus volume. The technique selected was the most advanced method available at the time the crania were made available for investigation. Despite further advances in CT Volume rendering techniques, the helical multislice scanner was the gold standard at the time of scanning.

Historically, Wolfowitz (1974) used standard x-ray views indicated for sinus investigation to calculate the volumes of the paranasal sinuses. X- ray technology, although a less expensive technique than computed tomography, was fraught with problems. The main problems were defined as the poor definition of the image and geometric distortion of the anatomy (Wolfowitz, 1974).

In traditional film radiography, the actual dimensions of anatomical structures can be estimated directly from the x-ray image after making corrections for geometric distortion (Koehler et al 1979). Most significantly, x-ray technology would result in a poor definition of anatomical landmarks. A thorough investigation of all volume rendering techniques, available at the time the crania were available to study, showed that helical multislice computed tomography was the ideal choice as it is the most advanced radiographic technique available to scan bony anatomy and yielded highly accurate reconstructions.

The reasons for selecting the Toshiba Asteion helical multislice computed tomographic scanner are detailed later in this chapter.

3.1.3 Selection Criteria

The Crania were selected for this study from the Raymond Dart Collection of Human Skeletons at the Department of Anatomy, University of Witwatersrand Johannesburg, South Africa. The collection of crania comprises several hundred crania in the various categories.

The skeletons of the Raymond Dart collection are catalogued according to race (geographic ancestry); and further separated into tribes from South Africa. The Zulu group came from the Zulu tribe. The Zulu tribe refers to the black South African population that comes from the Zululand area of Kwa Zulu Natal in South Africa. These crania were obtained from Zulu hospital patients who were Zulus according to their identity documents issued in South Africa. The Europeans were descendants of Europe to South Africa, who comprised a small European community in South Africa and who had donated their bodies to medical research.

The cost of CT scanning was a limiting factor in the number of crania selected for the study. Every effort was made to avoid selection bias as the entire collection could not be scanned. To this end, crania that met the inclusion criteria were randomly selected with the assistance of the laboratory and anatomy staff (who had no knowledge of the details of the study).

Fifty three (53) crania were selected from the Raymond Dart Collection. For the purposes of this research it was advantageous to have over 100 maxillary, ethmoid, sphenoid and frontal sinuses respectively to compare. As 53 crania met the selection criteria it was possible to analyse race and sex variations in the volumes of the maxillary, ethmoid, sphenoid and frontal sinuses by dividing the crania into 4 equal groups based on raceity and sex. The Zulu female group had one cranium more than the other groups because it was an extra cranium that fitted the selection criteria and therefore was worth investigating. The following selection criteria were applied:

1. **INCLUSION CRITERIA:**

i. The crania had to be intact and free from damage.

ii. Age: Adult crania were selected. Crania over age 16 were acceptable. This criterion was based on the findings of Uchida et al (1998) who found no significant age differences in the volume or linear measurements of the maxillary sinus. Sanchez Fernandez et al (2000) found that maxillary sinus volumes increase until 15 years of age and afterwards maintain similar values.

Similarly, the other paranasal sinuses were adult sinuses and therefore not expected to show any age variation. There was a slight unavoidable difference in ages for the different races: European males mean age 49.69 years; European Females 49.15; Zulu Males 43.31 and Zulu Females 37.00. The ages of Europeans are higher than those of Zulus (more so for females than for males) and therefore a possibility exists that there might be a slight confounding effect between race and age group.

iii. Race: One half of the sample had to be crania of European descent and the other half of the sample had to be Zulu crania. This criterion allowed for an race comparison.

iv. Sex: One half of the sample had to be male and the other half had to be female to allow for a sex comparison of the data.

v. Dentition: This was not considered a factor as Ariji et al (1994) found that the difference in right and left dentition had no influence on the maxillary sinus volume over the age of 20 years. This research used only 2 crania under the age of 20. Crania were therefore included regardless of the state of dentition. It should be noted that most of the crania had full dentition. Dentition has no bearing on the other paranasal sinuses.

2. EXCLUSION CRITERIA:

i. Crania of race groups other than Zulu and European were excluded.

ii. Damaged crania were excluded to ensure no bias.

iii. Crania with incomplete records were excluded.

3.1.4 Identification

Each cranium had been allocated a collection number (A. No) and a cadaver number (A.D. No) which is represented in the present study as A and C respectively. See Table 3.1.

TABLE 3.1. CRANIA LOCATION IN APPARATUS*

SCAN NUMBER	RIGHT LOWER LEVEL	LEFT LOWER LEVEL	RIGHT UPPER LEVEL	LEFT UPPER LEVEL
1	A2930 C4047	A3163 C4787	A2481 C3490	A3129 C4678
2	A2179 C2819	A2228 C3069	A2946 C4231	A2424 C3316
3	A2456 C3567	A1334 C1638	A2186 C3105	A3046 C4485
4	A2692 C3700	A3276 C5070	A2187 C3106	A2647 C3679
5	A1805 C2467	A2491 C3365	A3035 C4480	A2395 C3453
6	A3603 C6166	A3889 C7205	A3901 C7282	A3838 C6782
7	A3972 C7329	A3482 C5901	A1944 C2576	A1319 C1552
8	A1577 C2272	A1501 C2005	A1256 C1300	A381 C515
9	A1576 C2243	A2213 C2982	A1301 C1510	A1499 C2002
10	A1947 C2574	A2333 C3159	A2258 C3080	A943 C1007
11	A683 C684	A681 C676	A585 C628	A500 C491
12	A183 C2416	A430 C480	A697 C715	A491 C566
13	A520 C451	A530 C588	A380 C508	A595 C655
14			A399 C511	

A= Collection number / C= Cadaver number *Apparatus for scanning crania in CT machine detailed in section 3.2.

3.1.5 Demographics Of The Sample

This sample was comprised of 26 European crania and 27 Zulu crania. The tribal identification of the subjects examined in this study was recorded by hospital administrations. The Zulu crania were obtained from members of the same tribe. The European subjects examined this study are descendants of immigrants from different parts of Europe.

Table 3.2 identifies 13 European female crania used in this study. The corresponding age and date of death is recorded for each cranium. The mean age of the subjects from whom the crania were obtained is 49.69 years with the oldest being 75 and the youngest being 19 years.

TABLE 3.2 EUROPEAN FEMALE CRANIA

CRANIA NUMBER	AGE	DATE OF DEATH
A2930	49	30/09/1970
A3163	59	27/09/1976
A2481	59	16/11/1965
A3129	29	12/07/1975
A2179	19	23/12/1958
A2228	43	5/02/1961
A2946	50	18/12/1971
A2424	58	19/01/1964
A3603	46	12/06/1988
A3889	73	22/07/1994
A3901	75	4/11/1994
A3838	39	21/02/1992
A3972	47	16/04/1995

Table 3.3 identifies 13 European male crania used in this study. The corresponding age and date of death is recorded for each cranium. For cranium A1805, the ninth European male cranium scanned, no date of death was available to record and the cranium was marked "not specified". The mean age of the subjects from whom the crania were obtained is 49.15 years with the oldest being 59 years and the youngest being 31 years.

TABLE 3.3 EUROPEAN MALE CRANIA

CRANIA NUMBER	AGE	DATE OF DEATH
A2456	49	12/08/1966
A1334	47	17/09/1945
A2186	57	31/07/1961
A3046	32	19/10/1973
A2692	47	14/01/1968
A3276	58	15/09/1979
A2187	31	6/08/1961
A2647	54	3/10/1967
A1805	43	N/S
A2491	51	20/09/1964
A3035	55	30/10/1973
A2395	56	23/05/1965
A3482	59	10/09/1986

N/S = Not specified

Table 3.4 identifies 14 Zulu female crania used in this study. A corresponding age and date of death is recorded for each cranium. The mean age of the subjects from whom the crania were obtained is 37 years with the oldest being 60 years and the youngest being 20 years.

TABLE 3.4 ZULU FEMALE CRANIA

CRANIA NUMBER	AGE	DATE OF DEATH
A1944	60	7/08/1955
A1319	20	6/02/1945
A1577	60	15/08/1951
A1501	23	6/03/1948
A1256	32	23/11/1942
A381	29	4/10/1932
A1576	30	27/06/1951
A2213	35	20/07/1960
A1301	44	17/09/1944
A1499	27	5/12/1947
A1947	38	20/07/1955
A2333	40	22/07/1962
A2258	50	14/04/1961
A943	30	4/08/1940

Table 3.5 identifies 13 Zulu male crania used in this study. A corresponding age and date of death is recorded for each cranium. The mean age of the subjects from whom the crania were obtained is 43.31 years with the oldest being 90 years and the youngest being 16 years.

TABLE 3.5 ZULU MALE CRANIA

CRANIA NUMBER	AGE	DATE OF DEATH
A683	80	6/05/1935
A681	90	19/03/1935
A585	35	8/08/1934
A500	22	23/06/1932
A183	60	13/01/1926
A430	27	2/06/1932
A697	43	3/02/1936
A491	35	8/08/1933
A520	40	9/11/1931
A530	52	22/11/1933
A380	16	4/09/1932
A595	24	18/11/1934
A399	39	11/09/1932

3.2 APPARATUS

3.2.1 General Information

Before the introduction of computed tomography clinical radiography of the head required extremely accurate positioning of the cranium. Wolfowitz (1974), in his study of the pneumatisation of the skull of the South African Negro, specifically designed a perspex and stainless steel apparatus to secure the cranium and allow for accurate fixation, which had to be reproducible. This allowed for different radiographic views to be taken at the correct angles. Early authors such as Lysholm in 1931 described apparatus for accurate positioning of the head during radiography. Sassouni (1959) described the Broadbent-Bolton cephalometer – a standardised instrument used to position the head as accurately as possible in the Frankfurt plane (Wolfowitz, 1974).

Since the advent of computed tomography axial and coronal scans of the paranasal sinuses have replaced standard x-rays. Computed tomographic scans of the sinuses are taken in the direct coronal plane, i.e. perpendicular to the infraorbital meatal line. The plane of examination is determined by placing the head parallel to the required plane and by angling the gantry. Electronic manipulation of raw data allows for any plane to be reconstructed by the computer following completion of the scan (Stammberger, 1991).

3.2.2 Apparatus For Scanning Of Crania

Two plastic trays were vertically stacked and two laboratory bottles were used as spacers to increase the distance between the trays to allow for the crania to fit into the lower tray without touching the upper tray. The trays were selected to each accommodate 2 crania –placed side by side. With 2 crania in the lower tray and 2 crania in the upper tray, it was possible to scan the paranasal sinuses of 4 crania simultaneously in each frame. Each tray had a length of 400mm, a width of 300mm and a height of 140mm on each corner. The laboratory bottles separated the trays by an additional 55mm, thus the total height of the apparatus was 335mm. The bases of the crania were thus 195mm apart. The apparatus allowed for optimal scanning of the crania with minimal distortion at the selected settings.

3.3 RADIOGRAPHIC TECHNIQUES AND METHODS

The computer tomography was executed in the Linksfield Park Clinic in Johannesburg, South Africa with the permission of radiologists. It was undertaken here because of the proximity to the anatomical collection. Radiographers assigned to the scanner provided assistance with the scans. Assistance with the handling of the crania was obtained from the Department of Anatomy, University of the Witwatersrand. Computer application specialists from Tecmed (Toshiba Agents) provided assistance with data transfer to the workstation.

The Toshiba Multislice Helical Scanner selected for this study offered high precision, better sharpness, thin slices and volumetric calculations making it a good choice as it eliminated partial volume effects of the convential scanners.

The use of helical multislice scanning as opposed to traditional computed tomography was due to several advantages the helical multislice scanning process had compared to conventional scanning for this specifically for this research. The basic concept of conventional, helical and multislice scanning is discussed here in order to explain how the various types of computed tomography differ and why helical multislice computed tomography was an ideal choice for this research. Computed tomography was first introduced 30 years ago and has since become an integral part of clinical practice. Due to the enormous financial outlay involved when purchasing these machines there are many earlier models still available and operational. This meant that there was a selection of machines available from which to choose to conduct this research on. In the selection process the various types of scanners were researched and their method of operation investigated.

It should be reiterated that this study was conducted in Africa and that this represented the most advanced machine available at the time the crania were made available for scanning. Despite even more advanced CT technology that was developing regarding volumetric calculations, access in Africa was limited and this was the most advanced technique available for scanning the bony anatomy of the crania.

By today's standards early computed tomographic scanners were extremely slow and required enormous computer facilities to generate comparatively crude scans. Improvements in tube technology and computer hardware and software have shortened scan times and improved the resolution of scans. In first generation (conventional) scanners, the tube produces a narrow beam of x-rays that passes through the patient and is picked up by a row of detectors on the other side. The tube and detectors are positioned on opposite sides of a ring that rotates around the patient or cranium in the case of this study. The physical linkages between the power cables and the tube mean that the tube is unable to rotate continuously. After each rotation the scanner must stop and rotate in the opposite direction. Each rotation acquires an axial image, typically with a slice thickness of 1mm, taking approximately 1 second per rotation. The table moves the patient a set distance through the scanner between each slice (Garvey and Hanlon 2002).

The traditional computed tomographic machines were monoslice systems and therefore differed from helical systems. Monoslice systems are disadvantaged in that there is a considerable mismatch between the transverse (in plane) and longitudinal (axial) spatial resolution (Kopp et al 2000). In other words a two dimensional pixel was generated and a three dimensional voxel could not be produced. A voxel is a representation of a volume and has three dimensions i.e. an x, y and z axis.

In respect of this study:

Conventional scanners are limited particularly for a study such as this as the Scan time is slow which compromises accuracy. The scans are prone to artefacts, which could obscure the anatomy. The conventional scanners have a poor ability to reformat in different planes, studies of contrast are difficult, (in this research we have bone contrasting with air) and small areas between slices may be missed. The lack of accuracy (although small) would have a cumulative adverse effect on the overall volume obtained for the sinus and its ability to scan a slice as opposed to a volume of tissue would further compromise the accuracy of this research.

Spiral (helical) computed tomographic scanners were investigated for this research, as they are more appropriate than conventional scanners. In essence. they represent more advanced radiographic technology. The incorporation of slip ring technology into the design of scanners in the late 1980s removed the need for a rigid mechanical linkage between the power cables and the x- ray tube. This "simple" development, by enabling the tube to rotate in one direction indefinitely, re-established computed tomography at the forefront of imaging. While the tube is rotating, the table supporting the patient also moves continuously so that a volume of tissue rather than individual slices is scanned. The data is then reformatted automatically to display the images as axial slices. High quality reconstructed (reformatted) images in coronal; sagittal and oblique planes can be readily acquired on a workstation (Garvey and Hanlon 2002).

In respect of this study:

Spiral (helical) scanning has several advantages. The scan time is much shorter than that of conventional computed tomography. Closely spaced scans are readily obtained enhancing accuracy. Good quality reconstructions in different planes are possible with a spiral scanner. This would be advantageous to study the sinus and or to reconstruct the sinus and the likelihood that any small areas could be overlooked is less. The spiral scanner would generate a more accurate volume study than the conventional scanner. As the spiral scanner was not as fast as a multislice scanner and booked time on the machine would pose a problem (as the machines are in use in a hospital where time is money and scanning time is a critical factor as this was a large study involving many crania.) it was not the ideal choice. In its favour was the cost factor, as it is more cost effective to operate that the multislice machines, but due to the leap in technology with the multislice scanner the spiral scanner was not chosen

A multislice computed tomographic scanner could be considered as a “turbocharged” spiral (helical) scanner. Conventional and spiral scanners use a single row of detectors to pick up the x- ray beam after it has passed through the patient. Multislice scanners have many active rows of detectors (Garvey and Hanlon 2002).

In respect of this study:

The increased number of detectors and tube rotation times that take a fraction of a second combine to give faster coverage of a given volume of tissue. This is particularly advantageous for this research. Multislice scanners also come with faster computer software, offering increased reconstruction and post processing capabilities. As much of this research was conducted at the computed tomographic machine workstation these features were advantageous and featured in its selection as the apparatus of choice.

With a multislice machine a volume of tissue can be examined by using much finer slices and 1mm sections can be obtained. The multislice machine is excellent for its ability to measure 3-dimensional voxels that are representations of volume and therefore allows for reconstruction in any plane. This renders the machine highly accurate for the purpose of this study improving detail and facilitating reformatted images of better quality. Because scan time was a limiting factor in this study the time taken to perform a scan with a multislice scanner was many times faster than a single slice spiral scanner and this was advantageous.

In addition, multislice scanners generate an increased amount of data compared with single slice scanners. A study such as this generates an enormous amount of data. As the data was stored for a period of time on the machine and volumes were calculated from stored data it was advantageous to have a full picture archive on the machine. The volume of data resulting from studies of multislice computed tomography can pose considerable strain on storage systems and the Toshiba Asteion was adequately able to deal with the many slices. The operational programs were user friendly. The only limiting factor was the increased expense of using a helical multislice machine when compared to the single slice spiral machine and the increased time it took to analyse the extra data. An overall analysis showed than in view of the accuracy required the helical multislice computed tomographic machine was the ideal choice of scanning apparatus.

3.3.1 Methodology

Fifty-four crania (108 paranasal sinuses) in total were scanned in the coronal plane by a Toshiba Asteion helical multislice computed tomogram machine using the Brainlab protocol. The Brainlab protocol specifies particular computed tomographic machine settings and was used because it is a high-resolution thin slice program suitable for 3D reconstruction and image guided surgery. In essence, it gives the best picture of the paranasal sinuses. As the Brainlab protocol is a highly complex program indicated for image guided surgery on patients, it is beyond the scope of this study to detail it further other than to mention that it gave high resolution pictures and therefore enhanced accuracy of the study.

Four crania were scanned simultaneously in the apparatus. 1mm slices were obtained at the following machine settings: 120Kv, 200ma and reconstruction detail was set on large.

One mm slices were selected because it was assessed to be the ideal balance between accuracy and detail. In respect of this study, at 1mm slices exceptional detail is obtained. Each slice was hand traced to maximize accuracy. Although CT volume subtraction techniques had come available, they could not be used for paranasal sinus volume measurement calculations at the time because the sinuses are air filled cavities and with this technology, the volume of air was not subtractable. So a volume of the cavity could not be calculated. As each slice is hand traced a potential site of human error is limited by not doing an excessive number of tracings, which would occur if thinner slice settings of 0.75mm or 0.5mm were used.

Fifty-three crania (106 maxillary, ethmoid, frontal and sphenoid sinuses) were part of the comparative study and 1 cranium of indeterminate origin was additionally scanned. This cranium was made available for destruction and used for a general volumetric comparison using a dental silicone mould of the maxillary sinuses by water displacement measurement. The maxillary sinus was chosen for this purpose because of its accessibility. The silicone moulds also served as models of the maxillary sinus for further study.

Raw data was transferred from the scanner to a Vitrea 2 workstation. This data was also transferred to a laptop to allow viewing by Osiris Diacom Format. A CD was made of the raw data. A magnetic optical disc of the raw data was also made directly from the Toshiba Asteion computed tomographic scanner. Analysis of the data and volumetric calculations were made by tracing the outline of the paranasal sinuses with a cursor on the CT machine for each 1mm slice and totalling the number of slices for each sinus. The program of the Toshiba Asteion computer tomographic machine did a volumetric calculation for each sinus once all the tracings for each sinus were completed.

3.4. METHODS OF MEASUREMENT OF THE MAXILLARY, ETHMOID, SPHENOID, AND FRONTAL SINUSES.

3.4.1 Introduction.

In addition to the volumetric assessment of the sinuses additional measurements were taken to give as much extra information about the sinuses as possible. This was done with the intention of extending the study to investigate a classification of the sinuses according to their shape and to document any anatomical differences between the different groups of raceity, sex, and age. The information obtained will be relevant to surgeons operating endoscopically in this area and could also potentially be used for purposes of forensic identification in cases where other means are unavailable.

A. LENGTH, WIDTH AND HEIGHT MEASURMENT OF THE SINUSES

The paranasal sinuses are cavities and the length, width and height of all the sinuses were measured. These measurements were taken by scrolling through consecutive 1mm computer tomographic slices and taking measurements in order to identify the greatest length, width and height for each sinus. By measuring the greatest anteroposterior length, the greatest width and greatest vertical height, it can be seen which parameter contributes most to the variation in volume. Length, width, height and volume were analysed for statistical patterns related to race, sex.

B. ADDITIONAL MEASURMENTS: NASAL CAVITY WIDTH AND TOTAL DISTANCE ACROSS THE SINUSES.

Nasal cavity width (the distance between the medial walls of the left and right maxillary sinus of each cranium) was measured in the same way as maxillary lengths, widths and heights and related to the total distance (the outermost aspect of one maxillary sinus through to the outermost aspect of the opposite maxillary sinus). This was reflected as a ratio of nasal cavity width to total distance across the maxillary sinuses. Nasal cavity width was measured in order to establish if one race group had a bigger nasal cavity in relation to the maxillary sinuses than the other group. Nasal cavity width was also measured right across the nasal septum to avoid any septal deviations affecting the results. Total distance across the sinuses was measured in order to see if this measurement less the nasal cavity width showed any differences in the size of the sinuses. This was assessed by analysing the ratio of nasal cavity width to total distance. This ratio also suggests how the size of the maxillary sinuses relates to the size of the cranium. The size of the nasal cavity i.e. nasal cavity width in combination with the size of the maxillary sinus would influence ease of access into the maxillary sinus and therefore this cadaver study data would be clinically applicable to endoscopic sinus surgery techniques.

3.4.1.2 Analysis Of Live Patient Data

At a later date it was decided to analyse some data from patient scans from the differing race and sex groups to look for race and sex variations in the paranasal sinuses and to see if these findings support the findings of the original cadaver study. After obtaining advice from the William Harvey Research Institute about using data from patients, it was purported that this would be fine if the data was provided in an anonymised form by the radiology department to protect the identities of the patients. To this end the author approached the radiological practice of Drs Wedderburn Maxwell, radiologists practicing in Umhlanga Hospital, Kwa Zulu Natal, South Africa.

A senior radiographer was instructed to select CT scans that fully showed the sinuses of 40 adult patients. Selection bias was avoided as the radiographer - who had no knowlege of the details of the study - was instructed to take 40 sequential CT scans of European and Zulu male and female adult patients, that showed clear images of the paranasal sinus region. The Zulu patients were from the Zulu tribe of Kwa Zulu Natal and the European patients were from a European community living in Kwa Zulu Natal. These patients were all without sinus disease. Paranasal sinus CT scan data was acquired from the forty patients comprising ten European female patients, ten European male patients, ten Zulu female patients and ten Zulu male patients. These patients were all determined to have normal scans of the sinuses.

Owing to rapid advances in CT technology, the machine utilized was now a Toshiba Aquillion 64, a 64-slice machine. This CT machine was an updated version of the Toshiba Asteion that was used in the first part of the research, and thus expected to further enhance accuracy of paranasal sinus volumes and measurements.

Images were acquired in the axial plane by the 64-slice scanner. Slice thickness was 0.5mm Machine set to 120KV, 60mA and rotation time of 0.5 sec. Pitch factor was 0.64 and helical pitch of 41.

This data was provided and worked with in an anonymised format. A senior radiographer from the department assisted to undertake the same paranasal sinus measurements that were taken in the first part of the study.

The volume of data was constructed into coronal and sagittal slices on the workstation. The width and height of the paranasal sinuses were measured on the coronal reconstructions and the length was measured at the widest part of the sinus on the sagittal reconstruction.

Volume measurements were done by using axial images and the volume structure facility. Each sinus was drawn around through multiple slices and added as a structure. Each sinus was colour coded which then automatically gave a volume for each colour i.e. each sinus.

The results were recorded and analysed for race and sex variations in the paranasal sinuses.

CHAPTER 4: METHODS OF STATISTICAL ANALYSIS

4.1 Statistical Analysis Of The Crania And Sinuses

4.1.1 Data Sets, Statistical Software And Techniques

Data sets and measurements taken:
The maxillary, ethmoid, sphenoid and frontal sinus volumes, lengths, heights and widths were measured for European and Zulu male and female crania. The following data sets are used in the analysis.

1. Dried skulls. This data set which will be referred to as the "dried skulls" data set consisting of 53 crania of which, 14 were Zulu female, 13 European female, 13 Zulu male and 13 European male. In this data set nasal cavity width (ncw) and total distance (td) were also measured for each skull.

2. Live skulls. This data set will be referred to as the "live skulls" data set. These results were obtained from CT scans of 40 patients who had scans for non-sinus related issues. The above-mentioned measurements were recorded for each of 10 European males, 10 European females, 10 Zulu males and 10 Zulu females.

The following measurements were also taken on the crania:

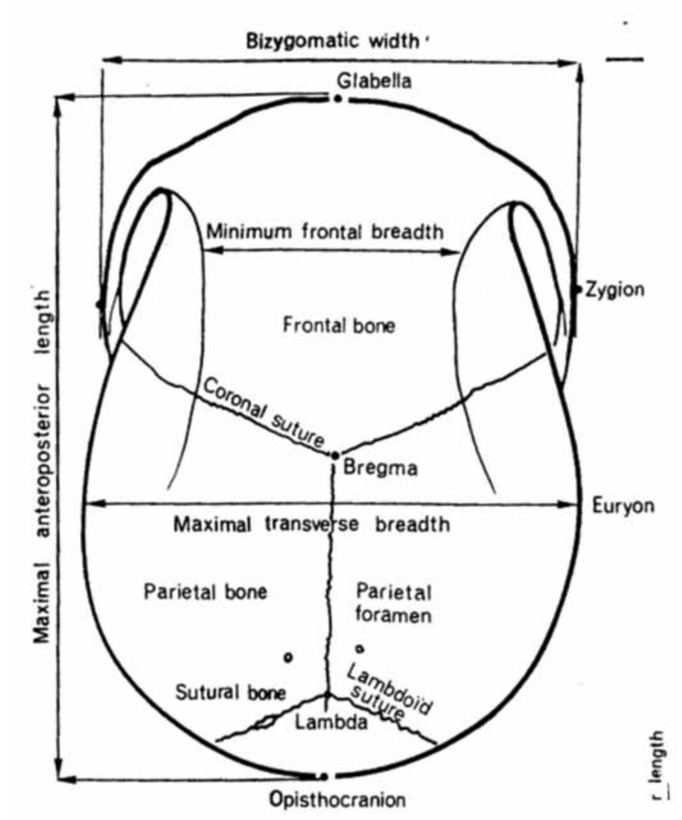
1 Head Circumference (headc)

2 Bizygomatic width at the Zygion (zygmw)

3 Maximum transverse width at the Eurion (headw)

These are shown in the diagram below.

FIGURE 4.1 DIAGRAMATIC REPRESENTATION OF THE CRANIUM DEMONSTRATING POSITIONING OF HEAD CIRCUMFERENCE, BIZYGOMATIC WIDTH AND MAXIMUM TRANSVERSE BREADTH



4.1.2 Statistical Software And Techniques Used

The statistical analyses are conducted by using the following software: SPSS (version 21), SAS (version 9.4) and R (version 2.11.1). Excel is used to prepare data for use by the other statistical software.

The techniques used can be classified into descriptive and inferential techniques.

The descriptive techniques to be used include the following.

1. The minimum, maximum, mean, standard deviation, standard error for each of the measurements.

2. Graphical techniques like box plots, clustered bar charts to describe possible differences between measurements for subgroups e.g. between sides (left and right), according to race (geographic ancestry), sex (biological sex) and the interaction between these.

The inferential techniques to be used include the following.

1. The confidence interval for the mean as a supplement to estimating the mean.

2. The Shapiro-Wilk test for normality to determine which follow-up ANOVA tests to be used.

3. Analysis of Variance (ANOVA) or Aligned Rank Transform (ART) ANOVA to test for differences between means according to factors race and sex.

4. The Wilcoxon paired samples test to test for differences between left and right side measurements.

5. Estimating Linear Discriminant analysis equations to be used for the classification of skulls according to race and sex.

4.1.3 PART 1 OF STATISTICAL ANALYSIS

An analysis of the "dried skulls" data set is performed. Race and sex differences are analysed for the different measurements of the paranasal sinuses. For each of the maxillary, ethmoid, sphenoid and frontal sinus volumes, lengths, heights and widths a fixed effects ANOVA is performed to determine whether there are differences according race, sex and race*sex (i.e. race and sex combined). Conclusions for the tests are reached by comparing the p-value for the test with 0.05 and regarding the test result as significant if p-value < 0.05 These tests are followed up by calculating means and 95% confidence intervals for each of the measurements according to race, sex and race*sex. Significant results and the reasons for their significance are recorded and later discussed.

4.1.4 Part 2 Of Statistical Analysis

The analysis in this section is also performed on the "dried skulls" data set. The analysis is done to show the minimum, maximum, mean and standard deviation for maxillary, ethmoid, sphenoid and frontal sinus volumes, lengths, heights and widths for the left and right side. These measurements are followed by results of Wilcoxon paired samples tests for differences between left and right measurements. The reasons for differences between left and right measurements that are found to be significant are illustrated by means of appropriate box plots.

ANOVA tests for differences between the various measurements (left and right side separately) for race sex and race*sex (i.e. age and sex combined) are performed. Significant differences are explained by presenting tables and bar charts of mean values.

For nasal cavity width (ncw) and total distance (td) the following results are to be presented.

1. Descriptive statistics (minimum, maximum, mean, standard deviation).

2. Test for differences according to race, sex and race*sex using ANOVA.

3. The tests referred to are followed up by presenting tables and bar charts explaining the reasons for significant results.

4.1.5 Part 3 Of Statistical Analysis

The analysis in this section is obtained from the "live skulls" data set. The results are recorded to show the minimum, maximum, mean and standard deviation for maxillary, ethmoid, sphenoid and frontal sinus volumes, lengths, heights and widths for European and Zulu males and females.

Shapiro-Wilk tests for normality are performed prior to performing ANOVA tests for differences between the various measurements according to race, sex and race*sex. The reason for performing these tests is that the variables used in the ANOVA are assumed to be normally distributed. If these tests show that variables are not normally distributed, modifications to the variables (e.g. a log transformation) need to be made or a test not sensitive to normality (like ART ANOVA) need to be performed instead of the standard ANOVA.

As for the "dried skulls" data set, significant results obtained from the ANOVA or ART ANOVA tests are to be explained by presenting tables and bar charts that show the reasons for significance.

4.1.6 Part 4 Of Statistical Analysis

Discriminant functions descriptions

In this section linear discriminant functions are estimated using the "dried skulls" data set. These functions are to be used to classify crania according to race and sex. The following functions are estimated.

1 Race and sex classification functions based on maxillary measurements and nasal cavity width.

(a) A race classification linear discriminant function using the logarithms of all the left and right side maxillary measurements.

(b) A sex classification linear discriminant function using the maxillary length (left and right), length squared (left and right), height squared (left and right), volume (left and right) and nasal cavity width measurements.

2. Race and sex classification functions based on ethmoid measurements.

(a) A race classification linear discriminant function using the logarithms of ethmoid volume (right), length (left and right), width (left and right), height (left and right), volume squared (left and right), length squared (left), width squared (left and right) and height squared (left) measurements.

(b) A sex classification linear discriminant function using the logarithms of ethmoid volume, length, width, height (left and right) as well as the squares of these measurements.

3. Race and sex classification functions based on sphenoid measurements.

(a) A race classification linear discriminant function using sphenoid volume (left and right), length (left and right), width (left and right), height (left and right), volume squared (left and right), length squared (left), width squared (left and right), height squared (left) measurements and volume, length, width and height left and right cross products.

(b) A sex classification linear discriminant function using the same variables as the sphenoid race classification function

4. Race and sex classification functions based on frontal measurements.

(a) A race classification linear discriminant function using frontal volume (left and right), length (left and right), width (left and right), height (left and right) and volume, length, width and height left and right cross products.

(b) A sex classification linear discriminant function using the same variables as the frontal race classification function.

5 Race and sex classification functions based on a combination of the maxillary, ethmoid, sphenoid and frontal measurements.

(a) A race classification linear discriminant function using all the ethmoid measurements (volume, length, width and height for left and right side), all frontal measurements (volume, length, width and height for left and right side) and all the sphenoid measurements except for height right (volume, length, width left and right side and height left side).

(b) A sex classification linear discriminant function using all the ethmoid and frontal (volume, length, width and height for left and right side) and the sphenoid volume (left and right side) measurements.

6 Race and sex classification functions based on a combination of the maxillary and ethmoid, td and ncw measurements.

(a) A race classification linear discriminant function using maxillary width, length, height (left and right side), ethmoid volume, width, length, height (left and right side) and td.

(b) A sex classification linear discriminant function using maxillary length, length squared, height squared, volume (left and right side), ethmoid volume (left and right side), length (left side), height (left and right side) and ncw.

4.2 THE THREE DIMENSIONAL MODEL OF THE MAXILLARY SINUS

A three dimensional model of the maxillary sinus was created by injecting dental silicone into the maxillary sinus. The maxillary sinus was chosen for this because of ease of access. This was performed on the unclassified skull, which was made available for destruction.

The two maxillary sinus moulds were assessed in respect of volume by the technique of water displacement. It would have been ideal to perform this technique on several skulls but due to the valuable nature of the Raymond Dart Collection and the unavailability of intact crania- that would need to be destroyed-this was not possible. The creation of the silicone model in itself was extremely valuable from an anatomical point of view as it showed the gross anatomical shape and orientation of the maxillary sinus cavity-which is not readily apparent from the computer tomographic images. This aspect of the study was conducted at a dental laboratory under the supervision of a prosthedontist, a sinus surgeon and a dental technician.

4.2.1 METHOD OF CREATION OF THREE DIMENSIONAL SILICONE MODELS TO INVESTIGATE THE SHAPE OF THE SINUS.

PLATE 1. CRANIUM FROM WHICH SILICONE MODELS OF MAXILLARY SINUSES WERE MADE.

Plate 1 depicts intact cranium at the prosthedontist's laboratory where this phase of the research was conducted. This cranium was scanned. A volume was calculated for each maxillary sinus for comparative purposes. At a later point the two silicone moulds of the sinuses moulds were 2 irregular shapes in a series of 5 objects that underwent volume calculation by water displacement in order to estimate error. It is necessary to re-iterate that only one cranium of unknown raceity and sex was available for destruction. This is due to the scarcity of anatomical material.

PLATE 2. CREATION OF OPENING IN CANINE FOSSA.

Plate 2 depicts the creation of an opening in the anterior wall of the maxillary sinus in the canine fossa. The opening was created using a Siemens TH40 dental hand piece with a cross cut fissure burr rotating at 20000 rpm in order to create a clean hole with minimal damage to the cranium.

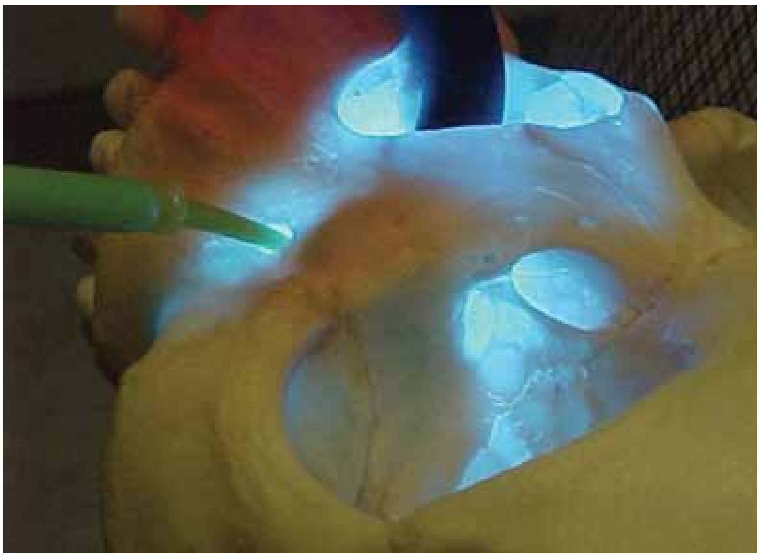


PLATE 3. DENTAL SILICONE INJECTION INTO THE ANTRUM.

Plate 3 depicts the insertion of cured polyvinyl siloxane dental silicone (Splash®). This is a low viscosity silicone that was selected so that the entire cavity could be optimally and easily filled. It was administered using a twin barrel syringe (Splash®). One barrel contained the silicone and a second barrel contained a rapid accelerant that resulted in rapid curing within 4 minutes. This procedure was done with transillumination to ensure complete filling.

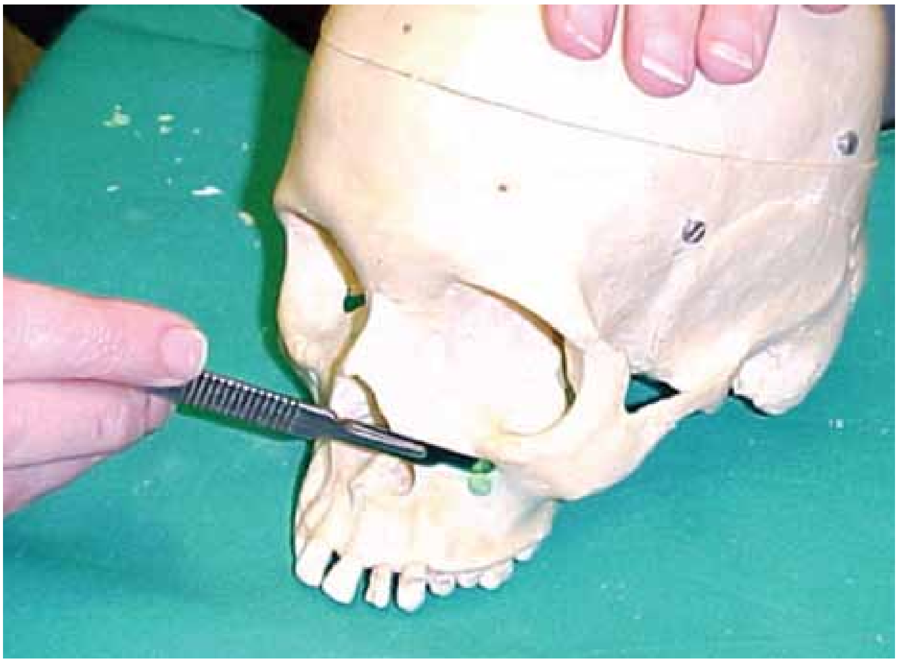


PLATE 4. TRIMMING OF SILICONE.

Excess silicone was trimmed from the entrance aperture using a Bard Parker® scalpel with a No. 15 blade.

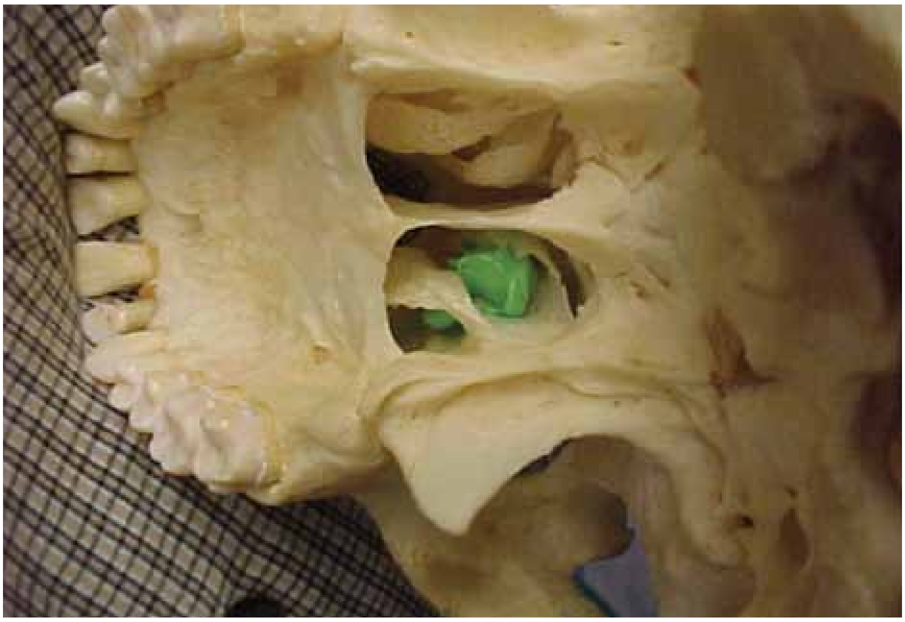


PLATE 5. TRIMMING OF SILICONE.

The excess silicone that protruded through the natural ostium of the maxillary sinus was trimmed level with the bony margins of the ostium.

PLATE 6. ***CREATION OF AN ADDITIONAL APERTURE.***

Due to an air pocket in the posterosuperior aspect of the maxillary sinus an additional aperture was created through which more silicone was inserted. This was created in order to insert more dental silicone into a region where an air pocket had formed. This procedure was performed on both sides.

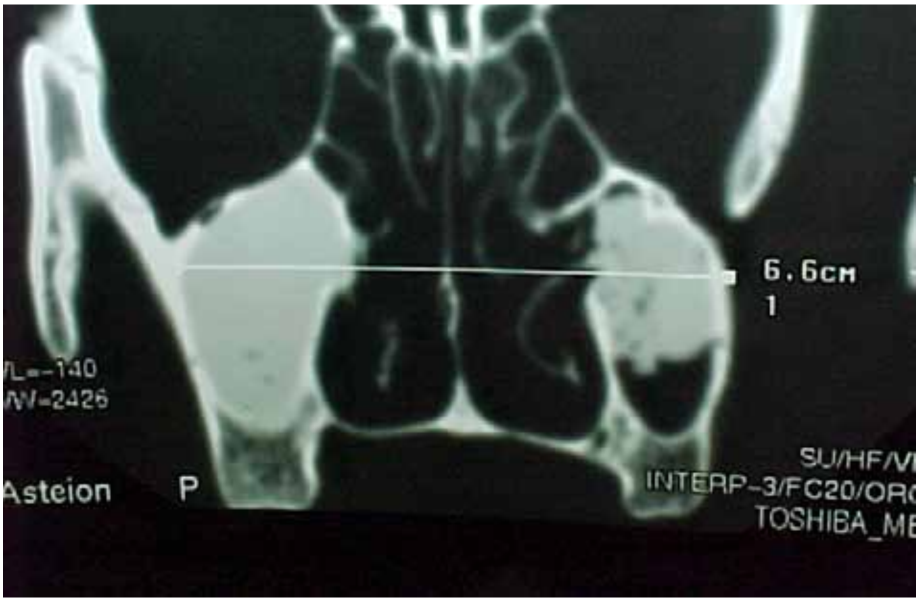


PLATE 7. ***SCAN SLICE PRINTED ON X-RAY FILM.***

The left maxillary sinus was incompletely filled. Technically filling the antrum is a difficult procedure and it became necessary to go back and fill the air pocket a third time.

PLATE 8. ADDITIONAL FILLING OF THE SINUS.

Additional apertures were created in the inferior portion of the sinus just above the alveolar ridge. Additional silicone was introduced through these apertures so that the remaining air pockets were eliminated.

PLATE 9. A FINAL X-RAY OF THE CRANIUM.

Plate 9 depicts a final x-ray of the cranium depicts the completely filled maxillary sinuses. This particular photo was taken after the silicone moulds had surgically been removed and replaced again hence the surgical saw cuts in the medial and lateral walls of the sinus.

The casts of the maxillary sinuses were carefully removed from the cranium. This was done by creating a tangential cut through the walls of a maxillary sinus under the guidance of the prosthedontist and a sinus surgeon. A Horico® single sided 1cm cutting disc was used for this part of the procedure. The inferior portion of the maxillary sinus including the alveolus was carefully removed and the casts were removed from the superior portion of the maxillary sinuses.

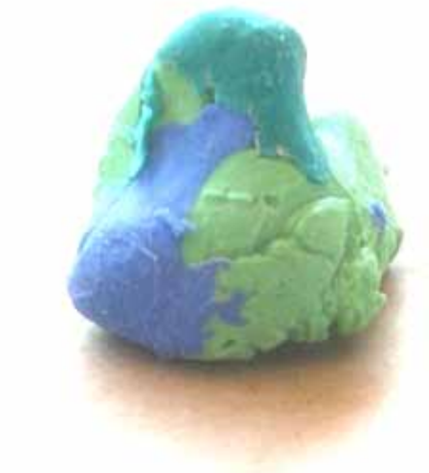


PLATE 10. A THREE DIMENSIONAL MODEL OF THE MAXILLARY SINUS

Plate 10 depicts the maxillary sinus where A is the apex and B is the base. The model had a flat base, which comprised the medial wall of the sinus. It had a rounded apex, which was consistent with a parabolic-hyperboloid shape.

PLATE 11. THE MEDIAL WALL OF THE MAXILLARY SINUS

Plate 11 shows the medial wall of the sinus with its characteristic flat quadrilateral shape.

Note1. Water displacement of the maxillary sinus model was performed to assess scanned volume versus CT volume measurement. This was undertaken to confirm accuracy of the volumetric scan analysis. Three additional objects were also scanned and had their scanned volume compared to their volume as calculated by water displacement when calculating least square mean differences.

The CT calculations were deemed to be accurate when compared to water displacement.

Note 2. To avoid destruction of a skull, modern technology would now permit for CT scanning a skull, then printing a 3D copy of the skull on a 3D Printer.

CHAPTER 5: RESULTS
PART I

In the investigation of race and sex differences in the paranasal air sinuses of European and Zulu dried crania the results presented below were obtained.

The results of the analysis of the maxillary, ethmoid, sphenoid and frontal sinus volumes and measurements of length, height and width are presented below:

In this section, statistical modelling was used to calculate least square mean differences between the races and sexes, and race by sex interactions were examined for volume, height, length, and width for each of the sinuses.

Comment: An alpha of 0.01 was used in the construction of 99% confidence intervals to identify as close as possible the minimum and maximum of possible values useable for identification purposes.

5.1 VOLUMETRIC RESULTS

A. MAXILLARY SINUSES

The volumetric analysis of the maxillary sinuses when, adjusted for age, yielded the following results:

Statistical analysis of the maxillary sinus volume revealed that the European crania had on average larger maxillary sinuses than Zulu crania and male crania had larger maxillary sinuses than female crania.

Europeans had the largest sinuses with an average volumetric measurement of 16.73 Range (14.86, 18.59) cm3.

Zulus had the smaller sinuses with an average volumetric measurement of 10.76 (8.94, 12.59) cm3.

The f-tests indicating statistically significant results (tested at $p<0.05$) are presented in table 5.1. LS-Means for race and sex are reflected in table 5.2

TABLE 5.1. TYPE lll TESTS OF FIXED EFFECTS MAXILLARY VOLUMES

EFFECT	F VALUE	PR > F
Race	35.91	0.0001
Sex	6.49	0.0141
Race*Sex	2.56	0.1161
Age	4.62	0.0367

Race was found to be highly significant with European sinuses being much larger in volume than Zulu sinuses (p <0. 0001), also there was conclusive evidence that there is a statistically significant difference between the sexes (p=0.0141). Age was shown to be a statistically significant factor but the interaction between race and sex was not, as there was not conclusive evidence demonstrating this. Sex was found to be significant with male sinuses (14.96 (13.14, 16.79)) cm3 having a larger volume than female sinuses (12.53 (10.74, 14.32)) cm3 (p =0.003)
*Type III tests examine the significance of an effect with all the other effects in the model.

TABLE 5.2. RACE, SEX AND RACE SEX LEAST SQUARES MEANS FOR MAXILLARY SINUS VOLUMES. ** (In all tables) Upper and lower refer to 99% confidence interval*

Race Least Squares Means					
RACE	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	16.7287	0.6952	0.01	14.8639	18.5935
Zulu	10.7642	0.6813	0.01	8.9368	12.5916

Sex Least Squares Means					
Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
Female	12.5297	0.6676	0.01	10.7391	14.3203
Male	14.9632	0.6804	0.01	13.1382	16.7883

*Race*Sex Least Squares Means*						
RACE	Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	Female	14.7461	0.9729	0.01	12.1367	17.3555
European	Male	18.7113	0.9702	0.01	16.1090	21.3136
Zulu	Female	10.3133	0.9559	0.01	7.7495	12.8771
Zulu	Male	11.2152	0.9606	0.01	8.6388	13.7916

While European male sinuses (18.71 (16.11, 21.31) cm3 were significantly larger than European female sinuses (14.75 (12.14, 17.36)) cm3 and similar findings were seen in the Zulu crania with Zulu males (11.22 (8.64, 13.79) cm3 being slightly larger than females (10.31 (7.75, 12.88)) cm3, there was not a significant difference found in the interaction between the two demonstrating that the difference between the European sexes was not statistically different from the difference found between the Zulu sexes.

B. ETHMOID SINUSES

Volumetric analysis of the Ethmoid sinuses revealed that European crania had larger ethmoid sinuses than Zulu crania and male crania had smaller ethmoid sinuses than females. European females had the largest sinuses with an average volumetric measurement of 5.09 (3.67, 6.51) cm3. While Zulu females had the smallest sinuses with an average volumetric measurement of 3.56 (2,00, 5,12) cm3.

TABLE 5.3. FACTORIAL ANOVA TYPE III TEST OF FIXED EFFECTS

EFFECT	F VALUE	PR > F
Race	5.56	0.0228
Sex	0.04	0.8470
Race*Sex	0.17	0.6823
Age	0.11	0.7362

The volumetric analysis of the ethmoid sinuses yielded the following results:

Race was found to be significant with European sinuses being larger in volume than Zulu sinuses (p =0.0228). Sex was found to not be significant with male sinuses having a much larger volume than female sinuses (p=0.8470). Race and sex interaction was found to be statistically insignificant (p=0.6823). LS Means and 95% confidence intervals are shown for race, sex, and race x sex in table 5.4.

TABLE 5.4. RACE, SEX AND RACE SEX LEAST SQUARES MEANS FOR ETHMOID SINUS VOLUMES

Race Least Squares Means					
RACE	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	4.9296	0.3773	0.01	3.9147	5.9445
Zulu	3.6218	0.3950	0.01	2.5594	4.6841

Sex Least Squares Means					
RACE	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
Female	4.3279	0.3886	0.01	3.9147	5.9445
Male	4.2235	0.3718	0.01	2.5594	4.6841

*Race*Sex Least Squares Means*					
RACE	Sex	ESTIMATE	ALPHA	LOWER	UPPER
European	Female	5.0928	0.01	3.6665	6.5191
European	Male	4.7665	0.01	3.3433	6.1896
Zulu	Female	3.5630	0.01	2.0020	5.1240
Zulu	Male	3.6805	0.01	2.2616	5.0994

C. SPHENOID SINUSES

Volumetric analysis of the sphenoid sinuses revealed that European crania had larger sphenoid sinuses than Zulu crania and male crania had smaller sphenoid sinuses than females. European females had the largest sphenoid sinuses with an average volumetric measurement of 4.27 (3.03, 5.52) cm3. While Zulu females had the smallest sinuses with an average volumetric measurement of 3.18 (1.96, 4.41) cm3. Mean, maximum and minimum values for race and sex are reflected in Table 5.5.

TABLE 5.5. TYPE lll TESTS OF FIXED EFFECTS SPHENOID VOLUMES

EFFECT	F VALUE	PR > F
Race	0.06	0.8033
Sex	0.15	0.6997
Race*Sex	4.50	0.0392
Age	1.09	0.3007

The volumetric analysis of the sphenoid sinuses yielded the following results: The only significant factor identified was the race x sex interaction (p=0.0392). Race was not found to be statistically significant with European sinuses slightly larger in volume than Zulu sinuses (p =0.803). Sex was not found to be significant with female sinuses having only a slightly larger volume than male sinuses (p =0.6997).

TABLE 5.6. RACE, SEX AND RACE SEX LEAST SQUARES MEANS FOR SPHENOID SINUS VOLUMES

Race Least Squares Means					
RACE	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	3.7010	0.3326	0.01	2.8089	4.5930
Zulu	3.5817	0.3259	0.01	2.7075	4.4559

Sex Least Squares Means					
Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
Female	3.7300	0.3194	0.01	2.8734	4.5866
Male	3.5527	0.3255	0.01	2.6797	4.4257

*Race*Sex Least Squares Means*						
RACE	Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	Female	4.2750	0.4654	0.01	3.0268	5.5233
European	Male	3.1269	0.4641	0.01	1.8820	4.3717
Zulu	Female	3.1850	0.4572	0.01	1.9585	4.4114
Zulu	Male	3.9785	0.4595	0.01	2.7460	5.2109

D. FRONTAL SINUSES

Volumetric analysis of the frontal sinuses revealed that European crania had larger frontal sinuses than Zulu crania and male crania had larger frontal sinuses than females but neither was shown to have statistically significant differences (table 5.7).

TABLE 5.7. TYPE III TESTS OF FIXED EFFECTS, FRONTAL SINUS VOLUMES

EFFECT	F VALUE	PR > F
Race	0.03	0.8625
Sex	2.03	0.1605
Race*Sex	0.14	0.7073
Age	0.71	0.4023

The European males had the largest frontal sinuses with an average volumetric measurement of 4.41 (2.11, 6.71) cm3. While the smallest frontal sinuses were found in the European females with an average volumetric measurement of 2.89 (0.58, 5.20) cm3. The age adjusted LS Means for race and sex are reflected in Table 5.8.

TABLE 5.8. RACE, SEX AND RACE SEX LEAST SQUARES MEANS FOR FRONTAL SINUS VOLUMES

Race Least Squares Means					
RACE	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	3.6505	0.6148	0.01	2.0016	5.2994
Zulu	3.4973	0.6024	0.01	1.8815	5.1132

Sex Least Squares Means					
Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
Female	2.9718	0.5903	0.01	1.3885	4.5551
Male	4.1761	0.6016	0.01	2.5623	5.7898

*Race*Sex Least Squares Means*						
RACE	Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	Female	2.8886	0.8602	0.01	0.5813	5.1959
European	Male	4.4125	0.8579	0.01	2.1115	6.7135
Zulu	Female	3.0551	0.8452	0.01	0.7881	5.3220
Zulu	Male	3.9396	0.8494	0.01	1.6615	6.2178

The volumetric analysis of the frontal sinuses yielded the following results:

Race was not found to be significant with European frontal sinuses not being much larger in volume than Zulu frontal sinuses (p =0. 8625). Neither was sex found to be statistically significant although male frontal sinuses were larger in volume than female frontal sinuses (p =0.1605). Race and sex interaction was also not found to be significant (p =0. 7073) with European male frontal sinuses being larger than European female frontal sinuses by a greater amount than Zulu male frontal sinuses are larger than Zulu female frontal sinuses but this difference was not statistically significant.

5.2 WIDTH RESULTS

A. MAXILLARY SINUSES

Statistical analysis of the maxillary sinus widths, when adjusted for age, revealed that the European crania had on average larger widths of maxillary sinuses than Zulu crania and male crania had larger maxillary widths than females. European females had the largest maxillary sinus widths with an average width measurement of 26.32 (23.52, 29.11) mm. The f-tests indicating statistically significant results (tested at p<0.05) are presented in table 5.9. The statistical analysis of the maxillary sinus widths yielded the following results:

TABLE 5.9. TYPE III TESTS OF FIXED EFFECTS, MAXILLARY SINUS WIDTHS

EFFECT	F VALUE	PR > F
Race	18.36	<. 0001
Sex	0.17	0.6822
Race*Sex	4.54	0.0384
Age	15.12	0.0003

The European females had the largest maxillary sinus widths with an average width measurement of 26.32 (23.52, 29.11) mm. Zulu females had the smallest maxillary sinus widths with an average width measurement of 19.56 (16.81, 22.31) mm. The age adjusted LS Means for race and sex are reflected in Table 5.10.

TABLE 5.10. RACE, SEX AND RACE SEX LEAST SQUARES MEANS FOR MAXILLARY SINUS WIDTHS

Race Least Squares Means					
RACE	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	25.4388	0.7454	0.01	23.4396	27.4381
Zulu	20.8664	0.7304	0.01	18.9072	22.8256

Sex Least Squares Means					
Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
Female	22.9417	0.7157	0.01	21.0219	24.8614
Male	23.3636	0.7295	0.01	21.4070	25.3203

*Race*Sex Least Squares Means*						
RACE	Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	Female	26.3205	1.0430	0.01	23.5230	29.1181
European	Male	24.5571	1.0402	0.01	21.7672	27.3471
Zulu	Female	19.5628	1.0248	0.01	16.8141	22.3114
Zulu	Male	22.1701	1.0298	0.01	19.4079	24.9323

The width analysis of the maxillary sinuses yielded the following results:

Race was found to be significant with European maxillary sinus widths being much larger than Zulu maxillary sinus widths ($p < 0.0001$). Sex found to not be statistically significant, although male sinuses were larger in width than female sinuses ($p = 0.6822$). Race and sex interaction was found to be significant ($p = 0.0384$) with European maxillary female sinuses being larger in width than European maxillary male sinuses and the Zulu male sinus widths were found to be larger than Zulu female sinus widths and this difference was statistically significant.

B. ETHMOID SINUSES

The width of the ethmoid sinus was measured by taking the maximum transverse width across the ethmoidal labyrinth on each side. The statistical analysis of the width measurements showed that:

Race was not found to be significant with European sinuses being only slightly wider than Zulu sinuses (p =0. 395). Sex was also found not to be significant (p = 0.450).The race and sex interaction was deemed to not be significant (p =0.7493).

TABLE 5.11. TYPE lll TESTS OF FIXED EFFECTS, ETHMOID SINUS WIDTHS

EFFECT	F VALUE	PR > F
Race	0.74	0.3954
Sex	0.58	0.4501
Race*Sex	0.10	0.7493
Age	0.38	0.5429

The age adjusted LS Means for race and sex are reflected in Table 5.12.

TABLE 5.12. RACE, SEX AND RACE SEX LEAST SQUARES MEANS FOR ETHMOID SINUS WIDTHS

Race Least Squares Means					
RACE	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	12.3145	0.4306	0.01	11.1562	13.4727
Zulu	11.7712	0.4508	0.01	10.5587	12.9836

Sex Least Squares Means					
Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
Females	11.8089	0.4435	0.01	10.6161	13.0017
Males	12.2768	0.4244	0.01	11.1354	13.4181

*Race*Sex Least Squares Means*						
RACE	Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	Female	12.1794	0.6052	0.01	10.5516	13.8072
European	Male	12.4496	0.6039	0.01	10.8254	14.0738
Zulu	Female	11.4384	0.6624	0.01	9.6569	13.2200
Zulu	Male	12.1039	0.6021	0.01	10.4845	13.7233

The width analysis of the ethmoid sinuses yielded the following results:

European male ethmoid sinus widths (12.45 (10.83, 14.07) mm) were slightly larger than European ethmoid female sinus widths (12.18 (10.55, 13.81) mm) and the Zulu male sinuses (12.10 (10.48, 13.72) cm) were also found to be larger in width than Zulu female sinuses (11.44 (9.66, 13.22) mm), yet this difference was not statistically significant.

C. SPHENOID SINUSES

The width of the sphenoid sinus was measured from the outermost point of the lateral wall of the sphenoid sinus, directly through to the septum for each sinus, to give maximum transverse breadth for each side. The statistical analysis of the sphenoid width measurements showed neither Race (p=0.650), Sex (p=0.763), or Sex x Race (p=0.106) to be significant but Age (p=0.301) was noted to be significant.

TABLE 5.13. TYPE lll TESTS OF FIXED EFFECTS, SPHENOID SINUS WIDTHS

EFFECT	F VALUE	PR > F
Race	0.21	0.6500
Sex	0.58	0.7631
Race*Sex	0.10	0.1060
Age	5.00	0.0301

The age adjusted LS Means for race and sex are reflected in Table 5.14.

TABLE 5.14. RACE, SEX AND RACE SEX LEAST SQUARES MEANS FOR SPHENOID SINUS WIDTHS

Race Least Squares Means					
RACE	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	15.8809	0.8497	0.01	13.6018	18.1600
Zulu	16.4364	0.8327	0.01	14.2029	18.6699

Sex Least Squares Means					
Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
Female	16.3356	0.8159	0.01	14.1471	18.5241
Male	15.9817	0.8316	0.01	13.7512	18.2122

Race*Sex Least Squares Means						
RACE	Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	Female	17.0215	1.1890	0.01	13.8323	20.2107
European	Male	14.7403	1.1858	0.01	11.5598	17.9208
Zulu	Female	15.6497	1.1682	0.01	12.5163	18.7832
Zulu	Male	17.2231	1.1740	0.01	14.0742	20.3719

The statistical analysis of the widths of the sphenoid sinuses yielded the following results

European sphenoid male sinus widths (14.74 (11.56, 17.92) mm) were smaller than European sphenoid female sinus widths (17.02 (13.83, 20.21) mm). The Zulu sphenoid male sinus widths (17.22 (14.07, 20.37) mm) were found to be slightly larger than Zulu sphenoid female sinus widths (15.65 (12.52, 18.78) mm) yet this difference was not statistically significant.

D. FRONTAL SINUSES

The width of the frontal sinus was measured from the outermost point of the lateral wall of the frontal sinus, directly through to the septum for each sinus, to give maximum transverse breadth for each side. The statistical analysis of the frontal width measurements showed neither Race (p=0.896), Sex (p=0.179), Sex x Race (p=0.295), or Age (p=0.285) was found to be significant.

TABLE 5.15. TYPE III TESTS OF FIXED EFFECTS, FRONTAL SINUS WIDTHS

EFFECT	F VALUE	PR > F
Race	0.02	0.8964
Sex	1.86	0.1785
Race*Sex	1.12	0.2953
Age	1.17	0.2850

The age adjusted LS Means for race and sex are reflected in Table 5.16.

TABLE 5.16. RACE, SEX AND RACE SEX LEAST SQUARES MEANS FOR FRONTAL SINUS WIDTHS

Race Least Squares Means					
RACE	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	25.3220	2.3485	0.01	19.0228	31.6212
Zulu	25.7619	2.3015	0.01	19.5889	31.9349

Sex Least Squares Means					
Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
Female	23.3388	2.2551	0.01	17.2902	29.3875
Male	27.7450	2.2984	0.01	21.5801	33.9099

*Race*Sex Least Squares Means*						
RACE	Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	Female	21.4082	3.2863	0.01	12.5936	30.2227
European	Male	29.2358	3.2773	0.01	20.4454	38.0263
Zulu	Female	25.2695	3.2288	0.01	16.6091	33.9299
Zulu	Male	26.2543	3.2447	0.01	17.5512	34.9573

The width analysis of the frontal sinuses yielded the following results:

European frontal male sinus widths (29.24 (20.45, 38,03) mm) were larger than European frontal female sinus widths (21.41 (12.59, 30.22) mm). The Zulu male frontal sinus widths (26.25 (17.55, 34.96) mm) were found to be slightly larger than Zulu female frontal sinus widths (25.27 (16.61, 33.93) mm), yet this difference was not statistically significant.

5.3 LENGTH RESULTS

A. MAXILLARY SINUS

The length of the maxillary sinus was obtained by taking the longest anterior to posterior measurement of the cavity. Statistical analysis identified significant differences between the races ($p<0.0001$) and age was found to be significant ($p=0.034$), while sex ($p=0.0916$) and interactions between race and sex ($p=0.761$) were not significant.

TABLE 5.17. TYPE III TESTS OF FIXED EFFECTS, MAXILLARY SINUS LENGTHS

EFFECT	F VALUE	PR > F
Race	21.09	<. 0001
Sex	2.96	0.0916
Race*Sex	0.09	0.7609
Age	4.74	0.0343

Europeans were found to have greater maxillary sinus lengths (39.80 mm (37.69, 41.90)) than Zulu maxillary sinuses (34.63 mm (32.57, 36.70)). Males had greater maxillary length (38.14 mm (36.08, 40.20)) than females (36.29 mm (34.26, 38.31)).

TABLE 5.18. RACE, SEX AND RACE SEX LEAST SQUARES MEANS FOR MAXILLARY SINUS LENGTHS

Race Least Squares Means					
RACE	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	39.7956	0.7854	0.01	37.6891	41.9021
Zulu	34.6325	0.7696	0.01	32.5682	36.6968

Sex Least Squares Means					
Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
Female	36.2851	0.7541	0.01	34.2624	38.3078
Male	38.1431	0.7686	0.01	36.0815	40.2046

*Race*Sex Least Squares Means*						
RACE	Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	Female	38.7012	1.0990	0.01	35.7536	41.6488
European	Male	40.8900	1.0960	0.01	37.9504	43.8296
Zulu	Female	33.8689	1.0797	0.01	30.9728	36.7650
Zulu	Male	35.3961	1.0851	0.01	32.4857	38.3064

European males (40.89 mm (37.95, 43.83)) and Zulu males (35.40 mm (32.49, 38.31) both had longer maxillary sinus lengths than females of their respective races, but these differences were not statistically significant. Both sex and race sex interactions were not significant.

B. ETHMOID SINUSES

The length of the ethmoid sinus was obtained by taking the longest anterior to posterior measurement of the cavity. Statistical analysis identified significant differences between the races (p=0.0284) was found to be significant, while sex (p=0.2663), age (p=0.6509) and interactions between race and sex (p=0.8212) were not significant.

TABLE 5.19. TYPE III TESTS OF FIXED EFFECTS, ETHMOID SINUS LENGTHS

EFFECT	F VALUE	PR > F
Race	5.13	0.0284
Sex	1.27	0.2663
Race*Sex	0.05	0.8212
Age	0.21	0.6509

Europeans were found to have a longer ethmoid sinus length (28.73 mm (25.77, 31.70)) than Zulu ethmoid sinuses (25.06 mm (21.95, 28.16)). Males had smaller ethmoid sinus lengths (26.01 mm (23.09, 28.93)) than females (27.78 mm (24.73, 30.84)).

TABLE 5.20. RACE, SEX AND RACE SEX LEAST SQUARES MEANS FOR ETHMOID SINUS LENGTHS

Race Least Squares Means					
RACE	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	28.7323	1.1030	0.01	25.7657	31.6989
Zulu	25.0593	1.1546	0.01	21.9540	28.1646

Sex Least Squares Means					
Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
Female	27.7809	1.1359	0.01	24.7258	30.8361
Male	26.0107	1.0869	0.01	23.0873	28.9340

Race*Sex Least Squares Means						
RACE	Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	Female	29.7963	1.5501	0.01	25.6271	33.9656
European	Male	27.6682	1.5467	0.01	23.5082	31.8283
Zulu	Female	25.7655	1.6965	0.01	21.2025	30.3285
Zulu	Male	24.3531	1.5421	0.01	20.2054	28.5008

European males (27.67 mm (23.51, 31.83)) and Zulu males (24.35 mm (20.21, 28.50) both had smaller ethmoid sinus lengths than females of their respective races (Cauc. Fem: 29.80 mm (25.63, 33.97)) and (Zulu Fem: (25.77 mm (21.20, 30.33)), but these differences were not statistically difference from each other.

C. SPHENOID SINUSES

The length of the sphenoid sinus was obtained by taking the longest anterior to posterior measurement of the cavity. Statistical analysis did not identify significant differences between the races (p=0.928), sexs (p=0.270), age (p=0.661), yet the interactions between race and sex (p=0.0027) was significant.

TABLE 5.21. TYPE III TESTS OF FIXED EFFECTS, SPHENOID SINUS LENGTHS

EFFECT	F VALUE	PR > F
Race	0.01	0.9276
Sex	1.25	0.2700
Race*Sex	10.02	0.0027
Age	0.19	0.6610

Europeans were found to have a slightly longer sphenoid sinus lengths (16.76 mm (14.07, 19.45)) than Zulu sphenoid sinuses (16.63 mm (13.99, 19.26)) but they were nearly identical lengths. Males had smaller sphenoid sinus lengths (15.93 mm (13.30, 18.56)) than females (17.46 mm (14.88, 20.04)).

TABLE 5.22. RACE, SEX AND RACE SEX LEAST SQUARES MEANS FOR SPHENOID SINUS LENGTHS

Race Least Squares Means					
RACE	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	16.7614	1.0020	0.01	14.0737	19.4491
Zulu	16.6303	0.9820	0.01	13.9965	19.2642

Sex Least Squares Means					
Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
Female	17.4641	0.9622	0.01	14.8833	20.0449
Male	15.9276	0.9807	0.01	13.2972	18.5580

*Race*Sex Least Squares Means*						
RACE	Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	Female	19.7137	1.4022	0.01	15.9527	23.4746
European	Male	13.8091	1.3983	0.01	10.0585	17.5598
Zulu	Female	15.2146	1.3777	0.01	11.5194	18.9098
Zulu	Male	18.0461	1.3844	0.01	14.3327	21.7595

European males (13.81 mm (10.06, 17.56)) and Zulu females (15.21 mm (11.52, 18.91)) both had smaller sphenoid sinus lengths than their counterparts within their respective races (Cauc. Fem: 19.71 mm (15.95, 23.47)) and (Zulu males: (18.05 mm (14.33, 21.76)), and these differences were statistically different from each other.

D. FRONTAL SINUSES

The length of the frontal sinus was obtained by taking the longest anterior to posterior measurement of the cavity. Statistical analysis did not identify significant differences between the races (p=0.165), sexes (p=0.362) or age (p=0.759). The interactions between race and sex (p=0.272) were insignificant.

TABLE 5.23. TYPE III TESTS OF FIXED EFFECTS, FRONTAL SINUS LENGTHS

EFFECT	F VALUE	PR > F
Race	1.98	0.1654
Sex	0.85	0.3622
Race*Sex	1.23	0.2720
Age	0.09	0.7596

Europeans were found to have a slightly longer frontal sinus length (9.61 mm (7.10, 11.22)) than Zulu frontal sinus lengths (7.61 mm (5.60, 9.63)). Males had larger sinuses (8.87 mm (6.86, 10.89) than females (7.90mm (5.92, 9.88)).

TABLE 5.24. RACE, SEX AND RACE SEX LEAST SQUARES MEANS FOR FRONTAL SINUS LENGTHS

Race Least Squares Means					
RACE	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	9.1601	0.7675	0.01	7.1016	11.2186
Zulu	7.6124	0.7521	0.01	5.5952	9.6296

Sex Least Squares Means					
Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
Female	7.9012	0.7369	0.01	5.9245	9.8778
Male	8.8714	0.7511	0.01	6.8568	10.8860

Race*Sex Least Squares Means						
RACE	Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	Female	8.0880	1.0739	0.01	5.2075	10.9684
European	Male	10.2322	1.0710	0.01	7.3597	13.1048
Zulu	Female	7.7143	1.0551	0.01	4.8842	10.5444
Zulu	Male	7.5105	1.0603	0.01	4.6665	10.3545

European males (10.23 mm (7.36, 13.10)) had longer frontal sinus lengths than European females (8.09mm (5.21 10.97). Zulu Females: 7.71 mm (4.88, 10.54)) had only slightly longer frontal sinus measurements than and Zulu males: (7.51 mm (4.67,10.35)), and these differences were not statistically different from each other. Race, sex and race sex interaction were insignificant.

5.4 HEIGHT RESULTS

A. MAXILLARY SINUS

The height of the maxillary sinus was measured from the uppermost point of the superior wall of the sinus directly through the sinus to the lowermost point of the inferior wall of the sinus. Race was identified to be significant (p=0.0002) while Sex (p=0.062), age (p=0.979), and race*sex interaction was not (p=0.520).

TABLE 5.25. TYPE lll TESTS OF FIXED EFFECTS, MAXILLARY SINUS HEIGHTS

EFFECT	F VALUE	PR > F
Race	16,92	0.0002
Sex	3.65	0.0621
Race*Sex	0.46	0.5027
Age	0.00	0.9796

Europeans were found to have larger maxillary sinus heights (36.44 mm (34.26, 38.61)) than Zulus (31.66 mm (29.53, 33.79)). Males (35.11 mm (32.98, 37.24)) were found to have larger height measurements than females (32.98 mm (30.89, 35.07)) but was only borderline statistically significant.

TABLE 5.26. RACE, SEX AND RACE SEX LEAST SQUARES MEANS FOR MAXILLARY SINUS HEIGHTS

Race Least Squares Means					
RACE	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	36.4378	0.8116	0.01	34.2610	38.6145
Zulu	31.6595	0.7953	0.01	29.5263	33.7926

Sex Least Squares Means					
Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
Female	32.9834	0.7793	0.01	30.8932	35.0736
Male	35.1139	0.7943	0.01	32.9835	37.2442

*Race*Sex Least Squares Means*						
RACE	Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	Female	34.9952	1.1356	0.01	31.9492	38.0412
European	Male	37.8803	1.1325	0.01	34.8427	40.9180
Zulu	Female	30.9715	1.1158	0.01	27.9788	33.9643
Zulu	Male	32.3474	1.1213	0.01	29.3400	35.3549

European males had the largest maxillary heights (37.88 mm (34.84, 40.92)) with European females next largest (34.99 mm (31.95, 38.04)) with Zulu males (32.35 mm (29.34, 35.35)) only being slightly larger in maxillary sinus height than Zulu females (30.97 mm (27.98, 33.96)).

B. ETHMOID SINUSES

The height of the ethmoid sinus was measured from the uppermost point of the superior wall of the ethmoidal labyrinth directly through the sinus to the lowermost point of the inferior wall of the ethmoidal labyrinth, to give the maximum height of the ethmoidal sinus.

None of the factors were found to be statistically significant from the modelling of the ethmoid height.

TABLE 5.27. TYPE III TESTS OF FIXED EFFECTS, ETHMOID SINUS HEIGHTS

EFFECT	F VALUE	PR > F
Race	0.90	0.3472
Sex	0.03	0.8689
Race*Sex	0.09	0.7619
Age	0.11	0.7449

Each of the factors demonstrated similar values of ethmoid height. European ethmoid heights (21.60 mm (18.42, 24.78)) were very close to the Zulu heights of (19.95mm (16.62, 23.28)). Females (20.91 mm (17.64, 24.19)) were similar to males (20.63 mm (17.50, 23.77)).

TABLE 5.28. RACE, SEX AND RACE SEX LEAST SQUARES MEANS FOR ETHMOID SINUS HEIGHTS

Race Least Squares Means					
RACE	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	21.5971	1.1826	0.01	18.4163	24.7779
Zulu	19.9454	1.2379	0.01	16.6159	23.2750

Sex Least Squares Means					
Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
Female	20.9113	1.2179	0.01	17.6355	24.1870
Male	20.6313	1.1654	0.01	17.4968	23.7657

*Race*Sex Least Squares Means*						
RACE	Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	Female	21.9943	1.6621	0.01	17.5241	26.4646
European	Male	21.1999	1.6584	0.01	16.7395	25.6603
Zulu	Female	19.8282	1.8190	0.01	14.9357	24.7207
Zulu	Male	20.0627	1.6535	0.01	15.6155	24.5098

European females had the largest heights, (21.99 mm (17.52, 26.46)) followed by European males (21.20 mm (16.74, 25.66)), then Zulu males were only slightly smaller (20.06 mm (15.62, 24.51)) with Zulu females being measured as the smallest of the classifications (19.83 mm (14.94, 24.72)), but the differences were not statistically significant.

C. SPHENOID SINUSES

The height of the sphenoid sinus was measured from the uppermost point of the sphenoid sinus directly through the sinus to the lowermost point of the of the sinus, to give the maximum height of the sphenoid sinus. None of the factors were found to be statistically significant from the modelling of the sphenoid sinus height.

TABLE 5.29. TYPE lll TESTS OF FIXED EFFECTS, SPHENOID SINUS HEIGHTS

EFFECT	F VALUE	PR > F
Race	0.00	0.9594
Sex	0.74	0.3935
Race*Sex	0.27	0.6038
Age	0.23	0.6316

Each of the factors demonstrated similar values of sphenoid height. Caucasian sphenoid heights (21.82 mm (19.05, 24.59)) were very close to the Zulu heights of (21.90mm (19.24, 24.55)). Females (21.25 mm (18.64, 23.86)) were smaller than males (22.46mm (19.75, 25.18)).

TABLE 5.30. RACE, SEX AND RACE SEX LEAST SQUARES MEANS FOR SPHENOID SINUS HEIGHTS

Race Least Squares Means						
RACE	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER	
European	21.8210	1.0320	0.01	19.0504	24.5915	
Zulu	21.8958	0.9904	0.01	19.2370	24.5546	

Sex Least Squares Means					
Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
Female	21.2535	0.9717	0.01	18.6448	23.8621
Male	22.4633	1.0111	0.01	19.7489	25.1776

Race*Sex Least Squares Means						
RACE	Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	Female	20.8478	1.4184	0.01	17.0400	24.6556
European	Male	22.7941	1.4676	0.01	18.8542	26.7341
Zulu	Female	21.6591	1.3899	0.01	17.9280	25.3903
Zulu	Male	22.1324	1.3985	0.01	18.3780	25.8868

European females had the smallest heights (20.85 mm (17.04, 24.66)), followed by Zulu females (21.66 mm (17.93, 25.39)). Zulu males (22.13 mm (18.38, 25.89)) were only slightly smaller in sphenoid sinus height than European males (22.79 mm (18.85, 26.73)) who had the largest sphenoid height measurements. The differences were not statistically significant.

D. FRONTAL SINUSES

The height of the frontal sinus was measured from the uppermost point of the frontal sinus on each side of the septum directly through the sinus to the lowermost point of the of the sinus, to give the maximum height of the frontal sinus on each side. Sex was found to be the only factor with significant differences between males and females (p=0.012).

TABLE 5.31. TYPE lll TESTS OF FIXED EFFECTS, FRONTAL SINUS HEIGHTS

EFFECT	F VALUE	PR > F
Race	0.07	0.7936
Sex	6.68	0.0128
Race*Sex	0.21	0.6515
Age	1.07	0.3064

European frontal sinus heights (22.88 mm (18.88, 26.87)) were similar to Zulu frontal sinus heights (22.32 mm (18.40, 26.23)). Male frontal sinus heights (25.24 mm (21.33, 29.16)) were significantly larger than female frontal sinus heights (19.95 mm (16.11, 23.79)).

TABLE 5.32. RACE, SEX AND RACE SEX LEAST SQUARES MEANS FOR FRONTAL SINUS HEIGHTS

Race Least Squares Means					
RACE	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	22.8780	1.4900	0.01	18.8816	26.8745
Zulu	22.3167	1.4601	0.01	18.4003	26.2331

Sex Least Squares Means					
Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
Female	19.9505	1.4307	0.01	16.1130	23.7880
Male	25.2443	1.4582	0.01	21.3330	29.1556

*Race*Sex Least Squares Means*						
RACE	Sex	ESTIMATE	STANDARD ERROR	ALPHA	LOWER	UPPER
European	Female	19.7649	2.0850	0.01	14.1726	25.3572
European	Male	25.9911	2.0793	0.01	20.4141	31.5682
Zulu	Female	20.1361	2.0485	0.01	14.6415	25.6306
Zulu	Male	24.4974	2.0586	0.01	18.9758	30.0190

European males had the largest frontal heights (25.99 mm (20.41, 31.57)) followed by Zulu males (24.50 mm (18.98, 30.02)). Zulu females frontal sinus heights (20.14 mm (14.64, 25.63)) were slightly larger than European females (19.76 mm (14.17, 25.36)). Race sex interaction was not significant.

PART 2: RESULTS

EXTENDED RESULTS: ANALYSIS OF THE FOUR PARANASAL

SINUSES

5.5 DESCRIPTIVE STATISTICS RESULTS AND TESTS CONCERNING MAXILLARY, ETHMOID, SPHENOID AND FRONTAL SINUS MEASUREMENTS

Results presented below were acquired from a more detailed analysis performed on SPSS, due to the need for analysing paranasal sinus measurements in further detail, looking at individual sinus sides and working towards an ability to classify crania according to their sinus volumes and measurements.

5.5.1 Notes On Data Layout Presented In Results

For each of 53 crania the following 8 measurements were made for maxillary, ethmoid, sphenoid and frontal sinuses: volume (left and right), length (left and right), width (left and right) and height (left and right). Of the 53 crania analysed here, 14 were Zulu female, 13 European female, 13 Zulu male and 13 European male. In addition to these 32 measurements the nasal cavity width and total distance were also measured for each skull. For three of the crania the ethmoid measurements were missing and for one the sphenoid sinus height measurements were missing.

In the results that follow all maxillary measurements will start with an m, ethmoid with an e, sphenoid with an s and frontal sinus measurements with an f. Volume will denoted by a v, length by l, height by h and width by w. Left hand side measurements will end with an l and right hand ones with an r. The nasal cavity width will be denoted by ncw and the total distance across the sinuses by td.

The purpose of the analysis is to summarize these measurements and to investigate differences between measurements according to race and sex.

TABLE 5.33 SUMMARY OF MAXILLARY MEASUREMENTS

	N	MINIMUM	MAXIMUM	MEAN	STD. DEVIATION
mwr	53	12	32	23.43	4.818
mwl	53	12	35	22.74	4.780
mlr	53	24	48	37.15	4.580
mll	53	24	49	37.15	4.825
mhr	53	25	48	34.04	4.844
mhl	53	24	43	33.94	4.982
mvr	53	4.68	27.52	13.71	4.726
mvl	53	4.97	25.68	13,66	4.704
Valid N (listwise)	53				

TABLE 5.34 SUMMARY OF ETHMOID MEASUREMENTS

	N	MINIMUM	MAXIMUM	MEAN	STD. DEVIATION
evl	50	.48	9.00	4.4404	2.07300
evr	50	.80	9.40	4.1680	2.03424
ell	50	14.80	38.70	27.0440	5.78641
elr	50	14.50	37.30	26.8380	6.14066
ewl	50	3.50	18.20	12.0500	2.49565
ewr	50	7.00	17.00	12.0840	2.18467
ehl	50	4.30	33.30	20.5220	6.07156
ehr	50	6.60	37.80	21.0960	6.26998
Valid N (listwise)	50				

TABLE 5.35 SUMMARY OF SPHENOID MEASUREMENTS

	N	MINIMUM	MAXIMUM	MEAN	STD. DEVIATION
svl	53	.08	8.90	3.3026	2.05751
svr	53	.27	10.20	3.9628	2.32974
sll	53	2.10	33.50	15.1774	6.26816
slr	53	4.30	31.40	18.1585	5.98297
swl	53	4.00	29.30	15.7189	5.82650
swr	53	6.00	38.50	16.5792	6.76545
shl	52	4.80	30.50	20.7346	5.70221
shr	52	8.50	37.00	22.9385	5.50042
Valid N (listwise)	52				

TABLE 5.36 SUMMARY OF FRONTAL MEASUREMENTS

	N	MINIMUM	MAXIMUM	MEAN	STD. DEVIATION
fvl	53	.05	10.40	3.8808	3.07029
fvr	52	.07	13.40	3.3100	3.40766
fll	53	1.30	19.70	8.6698	4.11791
flr	52	1.80	16.90	8.2327	4.04275
fwl	53	4.20	54.60	27.0849	13.49050
fwr	52	2.40	53.40	24.4500	12.74677
fhl	53	5.40	35.20	23.6415	7.73430
fhr	52	4.20	35.80	21.8731	8.34955
Valid N (listwise)	52				

5.5.2 Left Versus Right Measurements

The table below is a summary of Wilcoxon tests for the differences between left and right measurement for the variables.

TABLE 5.37 WILCOXON TESTS FOR DIFFERENCES BETWEEN LEFT AND RIGHT MEASUREMENTS

DIFFERENCE	Z	P-VALUE	COMMENT
mwl - mwr	-1.372	0.17	no significant difference
mll - mlr	-0.039	0.969	no significant difference
mhl - mhr	-0.467	0.641	no significant difference
mvl - mvr	-0.093	0.926	no significant difference
evr - evl	-1.229	0.219	no significant difference
elr - ell	-0.898	0.369	no significant difference
ewr - ewl	-0.204	0.838	no significant difference
ehr - ehl	-0.845	0.398	no significant difference
fvr - fvl	-2.336	0.019	fvl > fvr
flr - fll	-0.67	0.503	no significant difference
fwr - fwl	-0.628	0.53	no significant difference
fhr - fhl	-2.114	0.035	fhl>fhr
svr - svl	-1.395	0.163	no significant difference
slr - sll	-3.329	0.001	slr>sll
swr - swl	-0.584	0.559	no significant difference
shr - shl	-2.418	0.016	shr>shl

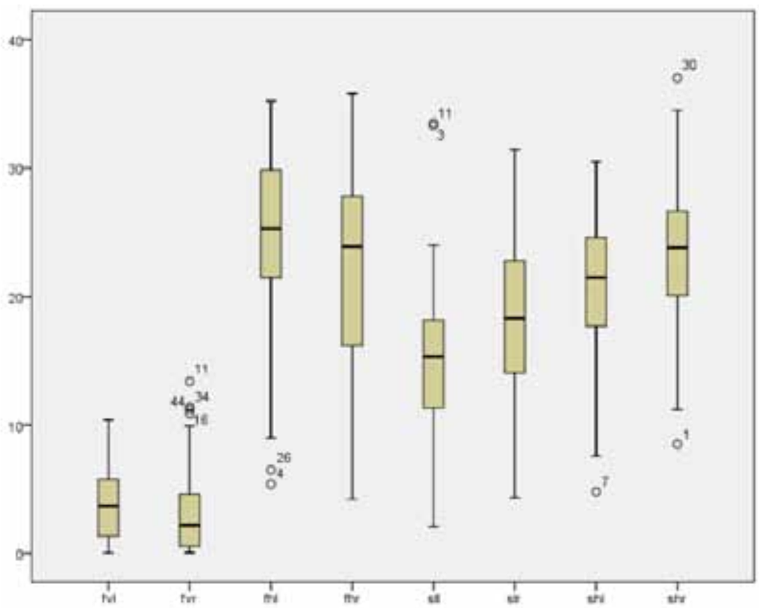
1 For **maxillary and ethmoid** measurements there are **no significant differences** between left and right measurements.

2 For **frontal measurements significant differences exist**; The left volume is significantly greater than the right volume and the left height is significantly greater than the right height. There are no significant differences between left and right measurements for lengths and widths.

3 For **sphenoid measurements significant differences exist;** The right length is significantly greater than the left length and the right height is significantly greater than the left height. There are no significant differences between left and right measurements for volumes and widths.

The significant differences described above are shown in the box plots that follow.

FIGURE 5.1 BOX PLOTS FOR VARIABLES WHERE LEFT AND RIGHT SIDE AVERAGE MEASUREMENTS ARE NOT EQUAL.



The above figure highlights the differences in right and left measurements of those sinus measurements that showed a significant difference between their right and left sides.

Due to the left and right side measurements not being the same for all the variables, comparisons according to race and sex will be done separately for the left and right hand sides.

5.5.3 Inferences Involving Race And Sex

The results shown in part (a) of the next 4 tables are summaries of Analysis of Variance (ANOVA) tests performed on SPSS.

TABLE 5.38 MAXILLARY MEASUREMENTS VERSUS RACE AND SEX

	RACE		Sex		RACE*Sex	
VARIABLE	F	P-VALUE	F	P-VALUE	F	P-VALUE
mwl	10.964***	0.002	0.17	0.682	2.29	0.137
mll	15.766****	0	1.334	0.254	0.024	0.878
mhl	19.13****	0	3.932	0.053*	0.454	0.504
mvl	27.458****	0	3.123	0.083*	1.713	0.197
mwr	4.545**	0.038	0.203	0.654	1.667	0.203
mlr	14.555****	0	2.984	0.09*	0.841	0.364
mhr	14.805****	0	2.826	0.099*	0.38	0.54
mvr	27.812****	0	7.073	0.011**	4.778	0.034**

* *Significant at the 10% level of significance*

** *Significant at the 5% level of significance*

*** *Significant at the 1% level of significance*

**** *Significant at the 0.1% level of significance*

- All maxillary sinus measurements are highly significant for difference between the races.
- Race Sex interaction is not significant

TABLE 5.39 MAXILLARY MEANS PER RACE GROUP

	EUROPEAN	ZULU
mwr	24.85	22.07
mwl	24.77	20.78
mlr	39.31	35.07
mll	39.54	34.85
mhr	36.35	31.81
mhl	36.54	31.44
mvr	16.39	11.13
mvl	16.42	10.99

- European crania have far larger maxillary sinus volumes and measurements of width, length and height than their Zulu counterparts

For all maxillary measurements, Europeans means > Zulu means.

TABLE 5.40 SIGNIFICANTLY DIFFERENT MAXILLARY MEANS PER SEX

Sex	FEMALE	MALE
mhl	32.78	35.15
mvl	12.72	14.62
mlr	36.19	38.15
mhr	33.04	35.08
mvr	12.38	15.09

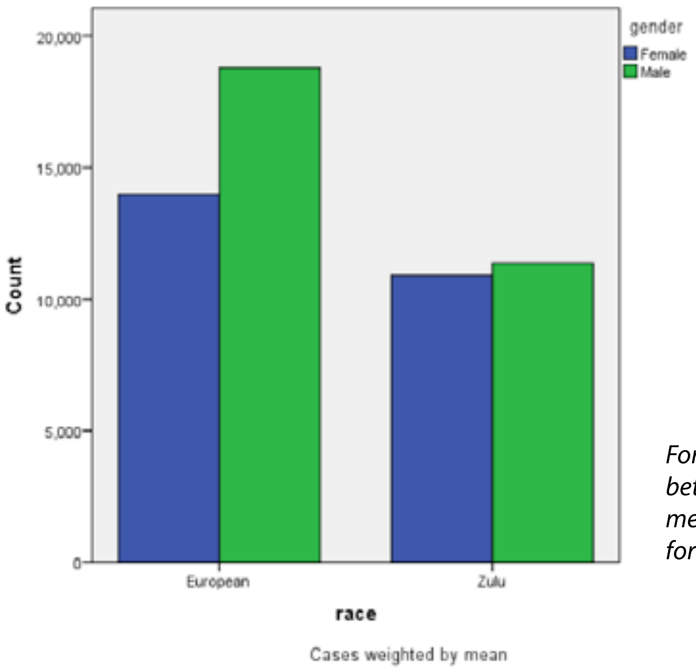
- Male crania have larger maxillary sinus volumes and measurements of length and height both found significant, than their female counterparts
- Maxillary width was not significant between males and females.

For all the above-mentioned variables, male means > female means.

TABLE 5.41 MAXILLARY RIGHT VOLUME MEANS PER RACE GROUP AND SEX

RACE	Sex	MEAN
European	Female	13.98
European	Male	18.80
Zulu	Female	10.90
Zulu	Male	11.37

FIGURE 5.2 MAXILLARY RIGHT VOLUME MEANS PER RACE GROUP AND SEX.



For Europeans the difference between the male and female means is much greater than that for Zulus.

TABLE 5.42 ETHMOID MEASUREMENTS VERSUS RACE AND SEX

	RACE		Sex		RACE*Sex	
VARIABLE	F	P-VALUE	F	P-VALUE	F	P-VALUE
ewl	0.733	0.396	0.751	0.391	0.165	0.686
ell	3.148*	0.083	2.013	0.163	0.014	0.907
ehl	0.941	0.337	0.533	0.469	0.333	0.567
evl	4.896**	0.032	0.042	0.838	0.008	0.93
ewr	0.193	0.663	0.193	0.663	0.008	0.93
elr	6.121**	0.017	0.633	0.43	0.237	628
ehr	0.534	0.468	0.132	0.718	0.001	0.981
evr	4.897**	0.032	0.036	0.851	0.432	0.514

- Ethmoid sinus measurements are significant for differences between the races.
- No Significance exists between sexes for ethmoid measurements
- Race Sex interaction is not significant in respect of the ethmoid sinus measurements.

TABLE 5.43 SIGNIFICANTLY DIFFERENT ETHMOID MEANS PER RACE GROUP

	EUROPEAN	ZULU
ell	28.4677	25.5125
evl	5.0538	3.7758
elr	28.8346	24.675
evr	4.7615	3.525

- European crania have larger ethmoid sinus volumes - left and right sides - and greater measurements of length than their Zulu counterparts.

For length and volume Europeans means > Zulu means.

TABLE 5.44 FRONTAL MEASUREMENTS VERSUS RACE AND SEX

	RACE		Sex		RACE*Sex	
VARIABLE	F	P-VALUE	F	P-VALUE	F	P-VALUE
fwl	0.008	0.931	0.231	0.633	0.802	0.375
fll	2.986	0.09*	0.038	0.846	1.754	0.191
fhl	0.054	0.818	2.377	0.13	0.359	0.552
fvl	0.004	0.947	2.128	0.151	0.731	0.397
fwr	0.248	0.621	3.855	0.055*	0.284	0.597
flr	2.305	0.135	1.768	0.19	0.193	0.662
fhr	1.623	0.209	10.651	0.002***	0.099	0.755
fvr	0.739	0.394	1.55	0.219	0.155	0.696

TABLE 5.45 FRONTAL LEFT LENGTH MEAN PER RACE

RACE	MEAN
European	9.6385
Zulu	7.737

Europeans mean > Zulu mean

- Frontal sinus measurements overall not significant.
- Significance exists for frontal height right between sexes with males greater than females.
- Race Sex interaction is not significant

TABLE 5.46 SIGNIFICANTLY DIFFERENT FRONTAL MEANS PER SEX

	FEMALE	MALE
fhr	18.3423	25.4038

TABLE 5.47 SPHENOID MEASUREMENTS VERSUS RACE AND SEX

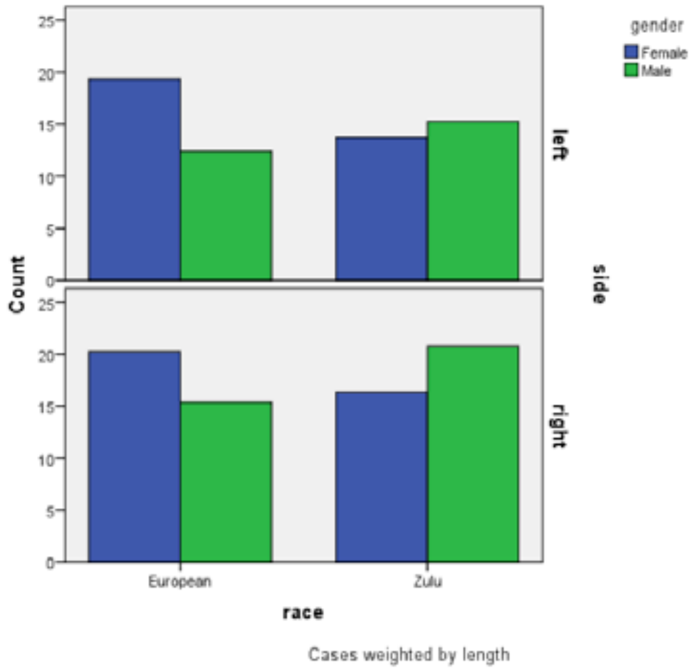
	RACE		Sex		RACE*Sex	
VARIABLE	F	P-VALUE	F	P-VALUE	F	P-VALUE
swl	0	0.992	0.809	0.373	2.243	0.141
sll	0.744	0.393	2.858	0.097	6.933	0.011**
shl	0.09	0.765	0.105	0.748	0.147	0.703
svl	0.515	0.476	0.102	0.75	2.607	0.113
swr	2.075	0.156	0.016	0.901	0.213	0.647
slr	0.235	0.63	0.022	0.882	8.847	0.005***
shr	0.002	0.968	1.315	0.257	0.428	0.516
svr	0.513	0.477	0.171	0.681	2.062	0.157

TABLE 5.48 SPHENOID LENGTH MEANS PER RACE GROUP, SEX AND SIDE

RACE	Sex	SLL	SLR
European	Female	19.3846	20.2462
European	Male	12.4154	15.3846
Zulu	Female	13.75	16.3714
Zulu	Male	15.2692	20.7692

- All sphenoid sinus measurements are not significant for difference between the races.
- Significance does not exist for sphenoid measurements between sexes
- Race Sex interaction is significant for sphenoid sinus length left and right.

FIGURE 5.3 SPHENOID LENGTH MEANS PER RACE GROUP, SEX AND SIDE



For Europeans the mean female length is greater than the male length. For Zulus the opposite is true. This means race sex interaction is positive for the sphenoid sinuses.

5.6 NASAL CAVITY WIDTH AND TOTAL DISTANCE ACROSS BOTH SINUSES

5.6.1 Nasal Cavity Width

This was measured from the lateral wall of the nasal cavity on one side, directly across the septum to the lateral wall on the opposite side. Note: individual sides were not measured because of variation of the septum position (deviated nasal septum) amongst individuals.

5.6.2 Total Distance (Across Both Sinuses)

Total distance was measured from the outermost point of the lateral wall of one maxillary sinus directly through the sinus across the nasal cavity through the opposite sinus to the outermost aspect of its lateral wall.

5.6.3 Summary And Inference For Nasal Cavity Width And Total Distance.

TABLE 5.49 SUMMARY FOR NASAL CAVITY WIDTH (NCW) AND TOTAL DISTANCE (TD)

	N	MINIMUM	MAXIMUM	MEAN	STD. DEVIATION
ncw	53	21	49	32.91	4.386
td	53	61	92	75.74	7.674
Valid N (listwise)	53				

TABLE 5.50 NASAL CAVITY WIDTH (NCW) AND TOTAL DISTANCE (TD) VERSUS RACE AND SEX

RACE		Sex		RACE*Sex		
VARIABLE	F	P-VALUE	F	P-VALUE	F	P-VALUE
ncw	1.021	0.317	8.002***	0.007	0.041	0.841
td	4.542**	0.038	2.496	0.121	4.213**	0.045

TABLE 5.51 NASAL CAVITY WIDTH (NCW) MEANS PER SEX

Sex	MEAN
Female	31.33
Male	34.54

Male > female

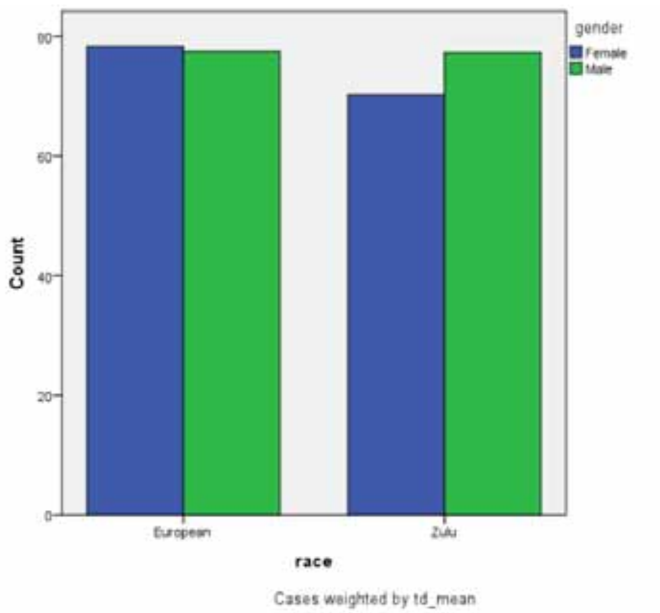
- Nasal cavity width measurements are not significant for race. European and Zulu crania don't exhibit much difference between each other in terms in nasal cavity widths.
- Significance exists for nasal cavity width measurements between sexes with males having larger nasal cavity widths than females.
- Race Sex interaction is not significant for nasal cavity width.

TABLE 5.52 TOTAL DISTANCE (TD) PER RACE GROUP AND SEX

RACE	Sex	MEAN
European	Female	78.38
European	Male	77.46
Zulu	Female	70.21
Zulu	Male	77.31

- Total Distance (across the sinuses) measurements are significant for race. Europeans have a larger total distance than Zulus.
- Sex is not significant with regards to total distance across the sinuses.
- Race Sex interaction is significant European males are slightly smaller than European females, whilst Zulu males were greater than Zulu females.

FIGURE 5.4 TOTAL DISTANCE (TD) PER RACE GROUP AND SEX



For Zulus the male mean is significantly greater than the female mean. For Europeans there is no difference between the means for the sexes.

RESULTS: PART 3

5.7 ANALYSIS OF LIVE PATIENT CT SCANS OF THE PARANASAL SINUSES

Results presented below were obtained from the CT scans of 40 patients who had scans for non-sinus related issues. Results of analysis of sinus measurements obtained are presented below.

The results of the analysis of 10 European males, 10 European females, 10 Zulu males 10 Zulu females are presented herewith. As for the dried crania, the maxillary, ethmoid, sphenoid and frontal analysis results for the live patients are recorded and presented.

Results obtained are documented to show differences between race, sex and race*sex interactions for the maxillary, ethmoid, sphenoid and frontal widths, lengths, heights and volumes of the live patient scans.

In the tables that follow, the variable names have the following meanings:

Variable names with first letters m, e, f and s refer to maxillary, ethmoid, frontal and sphenoid measurements respectively. Names with second letters w, l, m h and v refer to width, length, height and volume measurements respectively. Examples mw – maxillary width, fv – frontal volume, eh – ethmoid height, sl – sphenoid length.

TABLE 5.53 SUMMARY OF MAXILLARY MEASUREMENTS

		MW	ML	MH	MV
European female	Mean	26.67	36.89	32.585	14.604
	n	10	10	10	10
	minimum	21.75	32.45	26.8	11.22
	maxiimum	30.1	44.35	39.2	19.55
	Std. error	0.823887	1.158105	1.461507	0.832536
European male	Mean	28.965	39.88	37.43	18.698
	n	10	10	10	10
	minimum	23.6	32.9	29.75	11.09
	maximum	36.2	48.5	43.15	31.84
	Std. error	1.210235	1.474867	1.544188	2.024111
Zulu male	Mean	23.945	36.51	34.245	13.3205
	n	10	10	10	10
	minimum	18.9	28.75	28.65	9.59
	maximum	30.1	40.4	46.45	20.49
	Std. error	1.174909	1.55665	1.818721	1.20227
Zulu female	Mean	21.94	34.565	30.645	11.722
	n	10	10	10	10
	minimum	18.85	32.25	26.7	9.75
	maximum	25.05	38.7	34.7	13.4
	Std. error	0.69633	0.629818	0.906103	0.400107

TABLE 5.54 SUMMARY OF ETHMOID MEASUREMENTS

		EW	EL	EH	EV
European female	Mean	14.3705	37.015	26.47	9.071
	n	10	10	10	10
	minimum	10.21	32.7	20.35	6.98
	maximum	17.5	41	32.95	11.69
	Std. error	0.7531	0.852613	1.274366	0.554221
European male	Mean	15.84	37.02	29.875	11.0285
	n	10	10	10	10
	minimum	11.25	34.35	23.95	8.38
	maximum	20.35	41.35	33.85	13.76
	Std. error	1.025881	0.677749	1.143151	0.570282
Zulu male	Mean	18.235	37.22	23.545	8.4455
	n	10	10	10	10
	minimum	16.5	29.7	17.3	5.54
	maximum	19.8	45.3	28.7	11.62
	Std. error	0.301665	1.192644	1.043884	0.629992
Zulu female	Mean	17.315	38.15	23.31	7.879
	n	10	10	10	10
	minimum	13.15	32.8	18.5	4.58
	maximum	22.05	41.65	27.9	10.47
	Std. error	0.90554	0.812471	1.072945	0.617292

TABLE 5.55 SUMMARY OF FRONTAL MEASUREMENTS

		FW	FL	FH	FV
European female	Mean	20.79	16.455	17.675	3.1995
	n	10	10	10	10
	minimum	9.85	7.9	6.7	0.37
	maximum	36.5	29	38.9	8.29
	Std. error	3.038237	2.002642	3.180088	0.80141
European male	Mean	27.335	21.13	24.015	5.264
	n	10	10	10	10
	minimum	12.05	13.9	14.5	1.34
	maximum	42.2	28.75	38.4	11.66
	Std. error	2.647294	1.704344	1.975263	0.874547
Zulu male	Mean	26.12	29.3	24.47	5.2735
	n	10	10	10	10
	minimum	19.3	16.6	18.6	1.58
	maximum	35.2	44.1	34.4	9.75
	Std. error	2.045051	2.798034	1.519142	0.700252
Zulu female	Mean	29.255	28.925	24.505	5.0745
	n	10	10	10	10
	minimum	14.35	10.85	18.75	1.28
	maximum	41.05	41.85	29.1	7.8
	Std. error	2.409444	2.77561	1.130644	0.658617

TABLE 5.56 SUMMARY OF SPHENOID MEASUREMENTS

		SW	SL	SH	SV
European female	Mean	18.325	24.13	20.665	4.3095
	n	10	10	10	10
	minimum	11.7	10.15	12.15	0.65
	maximum	24.15	33.2	30.05	7.49
	Std. error	1.297375	1.97383	1.408842	0.60452
European male	Mean	19.52	26.71	23.49	6.428
	n	10	10	10	10
	minimum	13.5	15.95	14.95	2.02
	maximum	29.9	39.6	30.7	15.05
	Std. error	1.405863	2.01833	1.494726	1.140966
Zulu male	Mean	23.04	27.275	21.965	7.399
	n	10	10	10	10
	minimum	18.5	21.4	17.4	4.99
	maximum	27.65	32.2	24.65	9.41
	Std. error	0.879923	1.080054	0.818401	0.440989
Zulu female	Mean	20.11	23.5	20.645	5.933
	n	10	10	10	10
	minimum	16	17.75	14.45	3.36
	maximum	24.55	27.3	23.95	8.62
	Std. error	0.961301	1.099824	0.927524	0.558231

5.7.1 Tests For Normality Of Measurements

An Analysis of Variance (ANOVA) based on the F-test was performed to test for differences between races, sexes and race*sex interactions. This test is based on the assumption that the variables concerned are normally distributed. The tables below shows the results of Shapiro-Wilk tests for normality for each of the 16 variables concerned.

TABLE 5.57 SHAPIRO-WILK TESTS FOR NORMALITY

	WIDTH	LENGTH	HEIGHT	VOLUME
maxillary	0.9663(0.2741)	0.973(0.4466)	0.9399(0.0342)**	0.8355(0.00004)****
ethmoid	0.9827(0.7882)	0.9709(0.3849)	0.9627(0.2077)	0.9759(0.5409)
sphenoid	0.9839(0.8277)	0.9632(0.2150)	0.962(0.1961)	0.9418(0.0398)**
frontal	0.9752(0.5166)	0.9708(0.3801)	0.9633(0.2172)	0.9671(0.2906)

The entries without brackets in the above table are the W-statistics and those in brackets are the corresponding p-values.

** *Significant at the 5% level of significance.*

**** *Significant at the 0.1% level of significance.*

The above table suggested that the maxillary height, maxillary volume and sphenoid volume measurements were not normally distributed. One possible approach to achieve normality is to do a log transformation. The table below shows results of Shapiro-Wilks tests for the log transformed maxillary height, maxillary volume and sphenoid volume measurements.

TABLE 5.58 SHAPIRO-WILK TEST FOR NORMALITY OF LOG TRANSFORMED DATA

	HEIGHT	VOLUME
maxillary	0.9591(0.1561)	0.9201(0.0078)***
sphenoid	-	0.8594(0.00015)****

*** *Significant at the 1% level of significance.*

Only the log transformed maxillary measurements are normally distributed.

Based on the results of the 2 abovementioned tables,

1. ANOVA F-tests will be performed on all the measurements except maxillary height, maxillary volume and Sphenoid volume ones.

2. An ANOVA F-test will be performed on the log transformed maxillary height measurements.

3. Non-parametric ANOVA tests will be performed on maxillary volume and Sphenoid volume measurements.

5.7.2 Results Of Anova Tests For Effects Of Race, Sex And Race*Sex On Measurements

5.7.2.1 Maxillary Results

TABLE 5.59 RESULTS FOR RACE AND SEX FOR MAXILLARY MEASUREMENTS

	RACE	Sex	RACE * Sex
width: F	23.714	4.612	0.021
p-value	0****	0.039**	0.886
length: F	5.119	3.844	0.172
p-value	0.03**	0.058*	0.68
Height1: F	3.117	8.276	0.186
p-value	0.086*	0.007***	0.669
Volume2: F	12.235	3.807	1.1841
p-value	0.001267***	0.05886*	0.2838

1 ANOVA performed on log(height).

2 Aligned Rank Transform ANOVA performed on volume.

* *Significant at the 10% level of significance.*

** *Significant at the 5% level of significance.*

*** *Significant at the 1% level of significance.*

**** *Significant at the 0.1% level of significance.*

- All maxillary sinus measurements are significant for race.
- Volume is highly significant p=0.001 with Europeans having greater maxillary sinus volumes than their Zulu counterparts (16.65cm3, 12.52cm3).
- Width is highly significant p<. 001 (p=. 000)(27.81, 22,94)
- Length is significant p<. 05(p=0.03)(38.38, 35,54)
- Height is significant for sex, p=0.007

SIGNIFICANT EFFECTS

FIGURE 5.5 MAXILLARY MEANS PER RACE GROUP

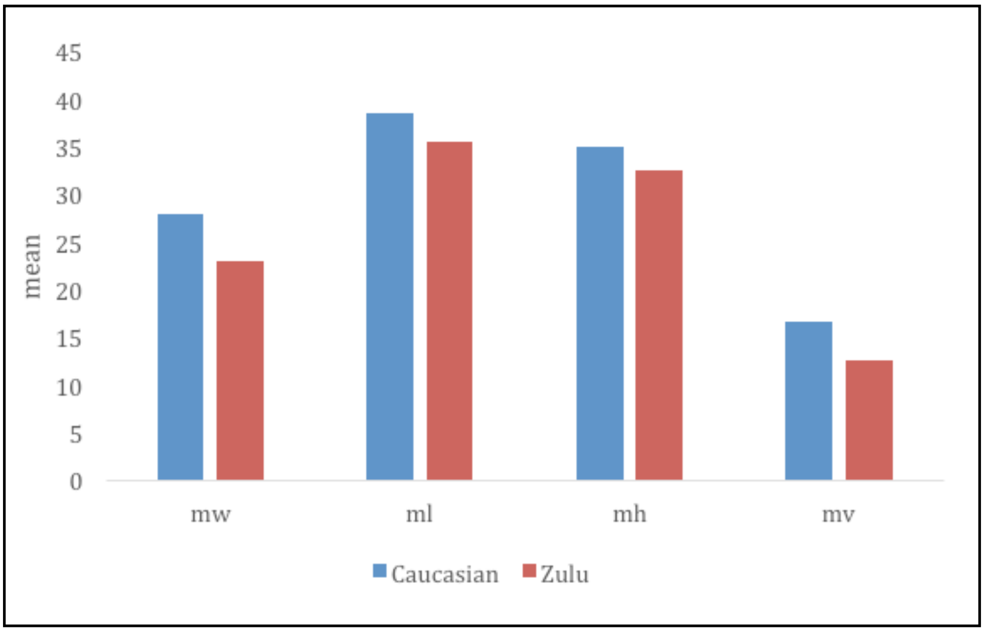


TABLE 5.60 MAXILLARY MEANS PER RACE GROUP

MEASUREMENT	EUROPEAN	ZULU
mw	27.8175	22.9425
ml	38.385	35.5375
mh	35.0075	32.445
mv	16.651	12.5212

The European maxillary measurements are greater than the corresponding Zulu ones.

FIGURE 5.6 MAXILLARY MEANS PER SEX

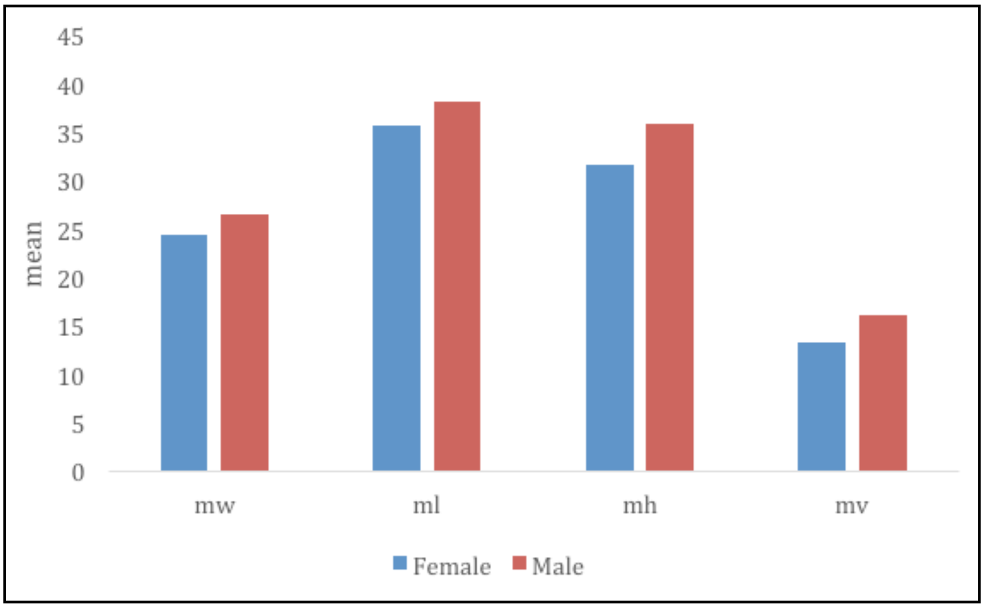


TABLE 5.61 MAXILLARY MEANS PER SEX

MEASUREMENT	FEMALE	MALE
mw	24.305	26.455
ml	35.7275	38.195
mh	31.615	35.8375
mv	13.163	16.0093

The male maxillary measurements are greater than the corresponding female ones.

- Maxillary sinus measurements are significant for difference between the races.
- Significance exists for maxillary measurements between sexes
- Race sex interaction is not significant

- Maxillary sinus measurements are significant for sex.
- Width is significant p<. 05 (p=. 039)(26.46mm, 24.31mm).
- Height is highly significant. p<. 05 (p=0.007) (35.84, 31.62).

5.7.2.2 *Ethmoid Results*

TABLE 5.62 TESTS FOR RACE AND SEX FOR ETHMOID MEASUREMENTS

	RACE	Sex	RACE * Sex
width: F	11.266	2.256	0.119
p-value	0.002***	0.142	0.732
length: F	0.545	0.262	0.267
p-value	0.465	0.612	0.608
height: F	17.414	2.562	1.943
p-value	0****	0.118	0.172
volume: F	10.105	4.517	1.372
p-value	0.003***	0.04**	0.249

- Ethmoid sinus measurements are significant for race.
- Volume is significant p<. 05, p=0.003 with Europeans having greater ethmoid sinus volumes than their Zulu counterparts (10.05cm3, 8.16 cm3).
- Width is significant p<. 05, (p=. 002)(15.11mm, 17.78mm) with Zulus having wider ethmoid sinuses than Europeans.
- Length is not significant
- Height is very significant p< .001, p=0.000 (28.17, 23.43) with Europeans much greater in ethmoid height than their Zulu counterparts.

SIGNIFICANT EFFECTS

FIGURE 5.7 ETHMOID WIDTH, HEIGHT AND VOLUME MEANS PER RACE GROUP

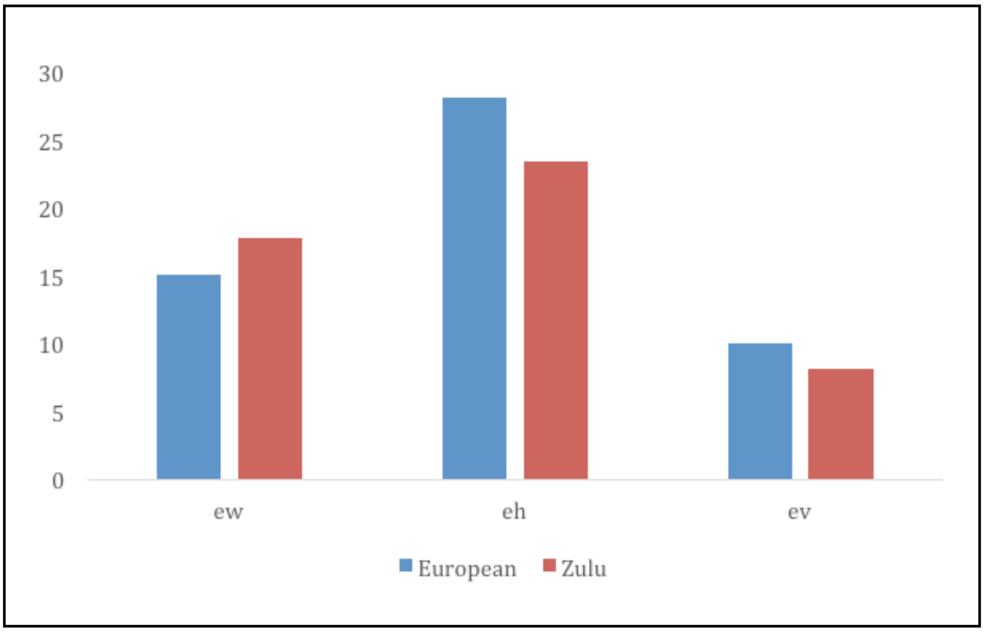


TABLE 5.63 ETHMOID WIDTH, HEIGHT AND VOLUME MEANS PER RACE GROUP

MEASUREMENTS	EUROPEAN	ZULU
ew	15.1053	17.775
eh	28.1725	23.4275
ev	10.0498	8.1622

The European heights and volumes are greater than the corresponding Zulu ones. The Zulu widths are greater than the corresponding European ones.

FIGURE 5.8 ETHMOID VOLUME MEANS PER SEX

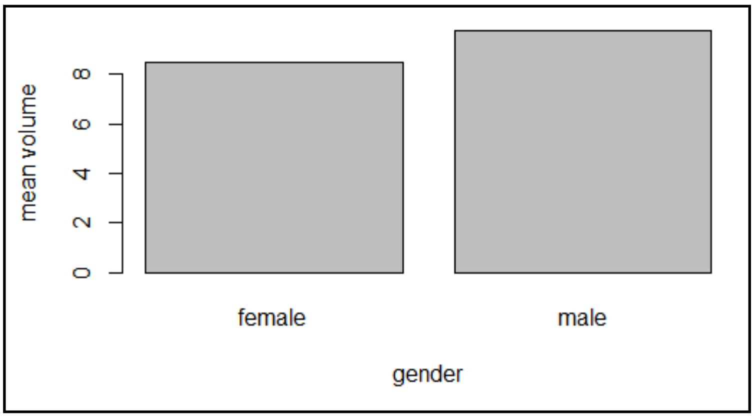


TABLE 5.64 ETHMOID VOLUME MEANS PER SEX

FEMALE	MALE
8.475	9.737

The male mean volume is greater than the female one.

- Ethmoid sinus measurements for volume are significant for sex.
- Volume is significant. p<. 05, p=0.04 with males having greater ethmoid sinus volumes than their female counterparts (9.74 cm3, 8.48 cm3).
- Width is not significant for sex.
- Length is not significant for sex.
- Height is not significant for sex.
- Race sex interaction is not significant.

5.7.2.3 Frontal Results

TABLE 5.65 TESTS FOR RACE AND SEX FOR FRONTAL MEASUREMENTS

	RACE	Sex	RACE * Sex
width: F	2.004	0.443	3.573
p-value	0.165	0.51	0.067*
length: F	18.977	1.136	0.824
p-value	0****	0.294	0.37
height: F	3.015	2.259	2.309
p-value	0.091*	0.142	0.137
volume: F	1.523	2.198	1.493
p-value	0.225	0.147	0.23

- Frontal sinus measurements are only slightly significant for race.
- Volume is not significant
- Width is not significant
- Length is however highly significant with the Zulus greater than the Europeans p<. 001(p=0.000)(18.79mm, 29.11mm)
- Height is only significant at the 10% level p=0.091 with the Zulus greater than the Europeans (20.85mm, 24.49mm)

SIGNIFICANT EFFECTS

FIGURE 5.9 FRONTAL LENGTH AND HEIGHT MEANS PER RACE GROUP

TABLE 5.66 FRONTAL LENGTH AND HEIGHT MEANS PER RACE GROUP

MEASUREMENT	EUROPEAN	ZULU
fl	18.7925	29.1125
fh	20.845	24.4875

The Zulu mean lengths and heights are greater than the corresponding European ones.

*FIGURE 5.10 FRONTAL WIDTH MEANS PER RACE*SEX GROUP*

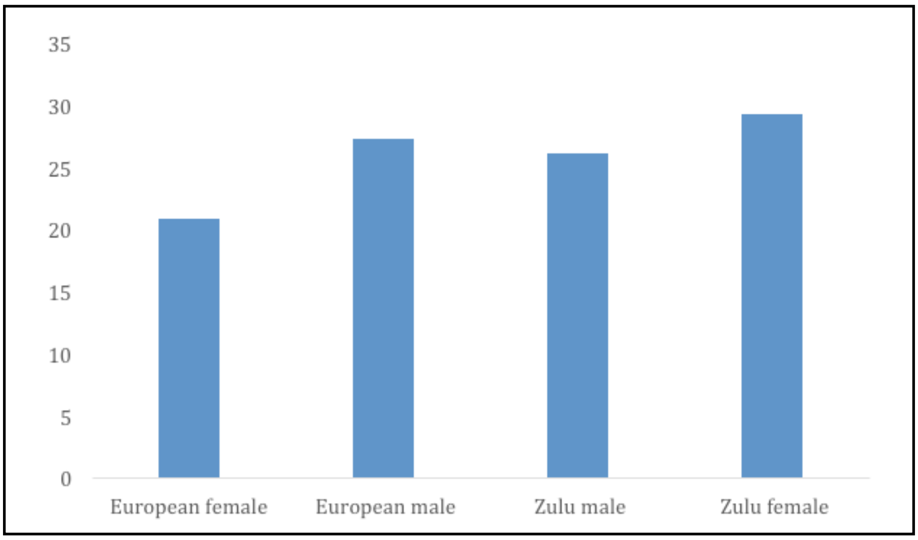


*TABLE 5.67 FRONTAL WIDTH MEANS PER RACE*SEX GROUP*

	MEAN WIDTH
European female	20.79
European male	27.335
Zulu female	29.255
Zulu male	26.12

For Europeans the male width is greater than the female one. For Zulus the opposite is true.

- Frontal sinus measurements are not significant for sex.
- Width is not significant for sex.
- Length is not significant for sex.
- Height is not significant for sex.
- Race sex interaction is significant for width at the 10%

Level p=. 067 with Zulu Females being greater in width than Zulu males while European males are greater in width than European females.

5.7.2.4 Sphenoid Results

TABLE 5.68 TESTS FOR RACE AND SEX FOR SPHENOID MEASUREMENTS

	RACE	Sex	RACE * Sex
width: F	5.253	3.176	0.562
p-value	0.028**	0.083*	0.458
length: F	0	3.904	0.138
p-value	0.984	0.056*	0.712
height: F	0.415	2.988	0.394
p-value	0.523	0.092*	0.534
Volume1: F	5.3595	6.6935	0.0244
p-value	0.02642**	0.01386**	0.8768

1 Aligned Rank Transform ANOVA performed on volume

SIGNIFICANT EFFECTS

FIGURE 5.11 SPHENOID WIDTH AND VOLUME MEANS PER RACE GROUP

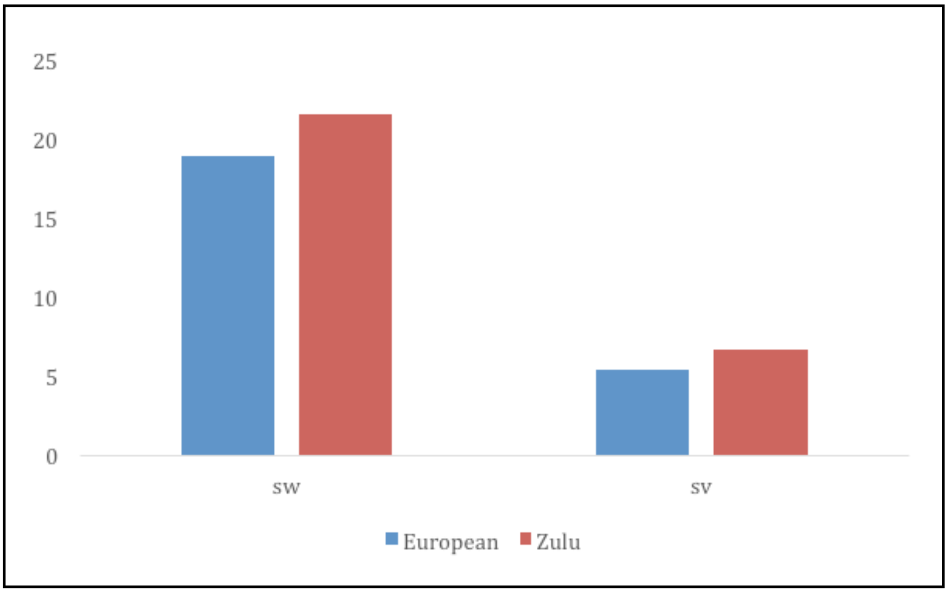


TABLE 5.69 SPHENOID WIDTH AND VOLUME MEANS PER RACE GROUP

MEASUREMENT	EUROPEAN	ZULU
sw	18.9225	21.575
sv	5.3688	6.666

Zulu width and volume means are greater than the corresponding European ones.

- Sphenoid sinus measurements are significant for race.
- Volume is significant p<. 05, with Zulus having greater sphenoid sinus volumes than their European counterparts (6.66cm3, 5.37cm3).
- Width is significant p<. 005 (p=. 028) (21.56mm, 18.92mm) with Zulus greater than Europeans.

FIGURE 5.12 SPHENOID MEANS PER SEX

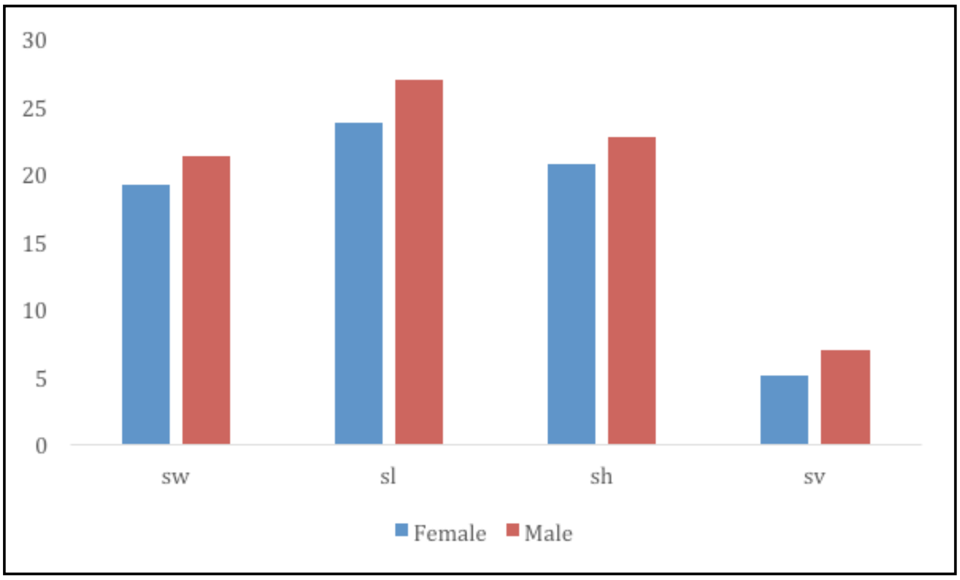


TABLE 5.70 SPHENOID MEANS PER SEX

MEASUREMENT	FEMALE	MALE
sw	19.2175	21.28
sl	23.815	26.9925
sh	20.655	22.7275
sv	5.1212	6.9135

The male means are greater than the corresponding female ones.

- Sphenoid sinus measurements are significant for sex.
- Volume is significant p<. 05, p=0.014 with males having greater sphenoid sinus volumes than their female counterparts (6.91cm3, 5.12 cm3).
- Width is significant at 10%level. (p=0.083) (21.28mm, 19.22mm). Males greater than females in width, length and height
- Length is significant at 10%level. (p=0.056) (26.99mm, 23.82mm).
- Height is significant at 10%level. (p=0.092) (22.73mm, 20.66mm).
- Race sex interaction not significant.

RESULTS: PART 4

5.8 CLASSIFICATION OF HUMAN CRANIA USING MAXILLARY, ETHMOID, SPHENOID AND FRONTAL SINUS MEASUREMENTS

Results presented in this section are the outcome of predictive classification of Zulu and European crania. Taking the results from the previous analyses, and searching for a classification formula to allow us to predict race and sex of the crania, the following results were obtained.

The purpose of the analysis is to use these measurements below (or functions of these measurements) to classify each of the skulls according to race (European or Zulu) and sex.

5.8.1 Notes On Data Layout Presented In Classification Results

For each of 53 human crania the following 8 measurements were made for maxillary, ethmoid, sphenoid and frontal sinuses: volume (left and right), length (left and right), width (left and right) and height (left and right). Of the 53 skulls 14 were Zulu female, 13 European female, 13 Zulu male and 13 European male. In addition to these 32 measurements the nasal cavity width and total distance were also measured for each skull. For three of the skulls the ethmoid measurements were missing and for one skull the sphenoid height measurements were missing.

5.8.2 Notation And Summary Of Classification Approach For These Results

5.8.2.1 Notation

All maxillary measurements will start with an m, ethmoid with an e, sphenoid with an s and frontal sinus with an f. Volume will denoted by a v, length by l, height by h and width by w. Left hand side measurements will end with an l and right hand ones with an r. The notation for a particular variable consists of the abbreviation for type (m, e, s or f) followed by the abbreviations for measurement (v, l, h or w) and side (l or r).

Examples: mvl denotes maxillary volume left; ehr denotes ethmoid height right.

5.8.2.2 Summary of procedure

The classification procedure according to race and sex was conducted as follows.

The linear discriminant function, which is a weighted sum of selected measurements or functions of selected measurements, was used for all classifications.

Each of the skulls was classified according to race (1 for Europeans, 0 for Zulus and sex (1 for male and 0 for female).

The classification function was found using the discriminant procedure under classify in SPSS.

5.9 CLASSIFICATION USING MAXILLARY SINUS MEASUREMENTS

5.9.1 Classification – Race

For each cranium a score (sum of weight* variable values) is calculated. The variables and weights used in the race classification function used are specified in the table that follows.

TABLE 5.71 VARIABLES AND COEFFICIENTS OF RACE LINEAR CLASSIFICATION FUNCTION

VARIABLE	WEIGHT
log(mwr)	-2.47009
log(mwl)	2.755338
log(mlr)	-10.19
log(mll)	8.355281
log(mhr)	3.192939
log(mhl)	-0.20096
log(mvr)	2.543715
log(mvl)	0.32073
constant	-31.8162

The classifications of the skulls are made according to the steps that follow:

1. Calculate the mean per race group for each variable shown in table 5.71

2. Calculate a score (sum of weight*mean values) for each race group.

3. Calculate the absolute difference (difference taken as positive irrespective of sign) of the skull score minus the score based on mean values for each race group (as explained in step 2).

4. Classify the skull as originating from the group with minimum absolute difference (as calculated in step 3).

Classification of Crania by Race

The above formula listed in table 5.71 may be written horizontally below:
The variable race was coded as race = 1 for European and race = 0 for Zulu.

The following classification function was found using the discriminant procedure under classify in SPSS.

r = -2.47009*lwr + 2.755338*lwl – 10.19*llr + 8.355281*lll + 3.192939*lhr – 0.20096*lhl + 2.543715*lvr + 0.32073*lvl – 31.8162 ,

where lwr = ln(wr), lwl = ln(wl) etc.

Classification rule for race. How to do it.

1 Calculate the means of the classification variables (lwr, lwl, llr, lll, lhr, lhl, lvr, lvl) for each of the 2 groups (race = 1 and race = 0).

2 Calculate the values r1 and r0 by substituting respectively the mean values for Europeans and Zulus obtained from the classification variables in step 1.

3 Calculate r for each skull.

If r is closer to r1, classify the skull as European (race = 1). If r is closer to r0, classify the skull as Zulu (race = 0).

For the data r1 = 0.854 and r0 = -0.823. A summary of the correctness of race classification according to this rule is shown in the table below.

This formula enables you to classify the crania according to race when applied to the maxillary sinus measurements.

A summary of the correctness of race classification according to this rule is shown in the table below.

TABLE 5.72 CLASSIFICATION RESULTS FOR RACE

	RACE/CLASSIFICATION	ZULU	EUROPEAN	TOTAL
Count	Zulu	23	4	27
	European	1	25	26
%	Zulu	85.2	14.8	100
	European	3.8	96.2	100

90.6% of original grouped cases correctly classified.

From the above table it can be seen that 48 of the 53 skulls **(90.6%) were correctly classified** and 5 skulls (9.4%) incorrectly classified.

- Using the above formula 90.6 % of the crania are correctly classified according to race. This classification is entirely based on the measurements obtained by CT scan of the maxillary sinus.

5.9.2 Classification – Sex

The initial classification according to sex is done by using the same approach as explained for race. The main results are shown in the tables that follow.

TABLE 5.73 VARIABLES AND COEFFICIENTS OF SEX LINEAR CLASSIFICATION FUNCTION

VARIABLE	WEIGHT
mlr	-3.16029637
mll	1.827259302
mlrs	0.045376875
mlls	-0.02682328
mhrs	-0.00027482
mhls	0.001709737
mvr	0.0000307851
mvl	-0.000024268
ncw	0.175188577
constant	16.05280573

The variables ending with an s are squares e.g. mlrs = mlr*mlr, mlls =mll*mll, mhrs = mhr*mhr. ncw – nasal cavity width.

Sex classification of crania

The variable sex was coded as sex = 1 for male and sex = 0 for female.

The following classification function was found using the **discriminant** procedure under **classify** in SPSS.

g = -3.16029637*lr + 1.827259302*ll + 0.045376875*lrs – 0.02682328*lls –

0.00027482*hrs + 0.001709737*hls + 0.0000307851*vr – 0.000024268*vl +

0.175188577*cw + 16.05280573,

where lrs = lr*lr, lls = ll*ll etc.

Classification rule for sex

The classification rule is applied as explained in the race classification prior, with grouping variable sex (sex = 1 for male and sex = 0 for female) and the above mentioned as classification variables.

When substituting the mean values for the classification variables for males and females into the above equation, the function has values g1 = 0.744 and g0 = -0.716 respectively.

A skull with a value of g closer to g1 is classified as male and one with a value closer to g0 as female. A summary of the correctness of sex classification according to this rule is shown in the table below.

TABLE 5.74 CLASSIFICATION RESULTS FOR SEX

	Sex/CLASSIFICATION	FEMALE	MALE	TOTAL
Count	female	25	2	27
	male	6	20	26
%	female	92.6	7.4	100
	male	23.1	76.9	100

84.9% of original grouped cases correctly classified.

From the above table it can be seen that 45 of the 53 skulls (84.9%) were correctly classified and 8 skulls (15.1%) incorrectly classified.

- *Using the above formula 84.9 % of the crania are correctly classified according to sex. This sex classification is entirely based on the measurements obtained by CT scan of the maxillary sinus.*

5.10 ETHMOID SINUS CLASSIFICATIONS

5.10.1 Classification – Race

The following variables gave the best classification results.

For race: The log (base e) of each of the above mentioned variables together with their squares.

This resulted in 74% of the skulls being correctly classified according to race.

TABLE 5.75 COEFFICIENTS OF THE ETHMOID CLASSIFICATION FUNCTION FOR RACE

VARIABLE	COEFFICIENT
levr	0.832
lell	3.132
lelr	-63.821
lewl	0.709
lewr	3.913
lehl	-17.157
lehr	2.903
levlsq	-0.01
levrsq	0.071
lellsq	-0.779
lewlsq	9.98
lewrsq	-0.848
lehlsq	2.992
constant	-0.702

evls = evel*evl, evrs = evr*evr, ells = ell*ell, ewls = ewl*ewl, ewrs = ewr*ewr, ehls = ehl*ehl.

5.10.2. Classification – Sex

For sex: each of the above mentioned variables together with their squares. This resulted in 78% of the skulls being correctly classified according to sex.

TABLE 5.76 COEFFICIENTS OF THE ETHMOID CLASSIFICATION FUNCTION FOR SEX

VARIABLE	COEFFICIENT
evl	-1.888
evr	0.804
ell	0.719
elr	-0.337
ewl	-1.345
ewr	2.222
ehl	-0.15
ehr	-0.707
evlsq	0.122
evrsq	-0.057
ellsq	-0.011
elrsq	0.008
ewlsq	0.056
ewrsq	-0.096
ehlsq	0.009
ehrsq	0.012
constant	-0.873

All the variables ending with an s are squares.

Race and Sex classification of crania using Ethmoid Sinus Measurements

In the same manner that the formulae for the classification of crania according to the measurements of the maxillary sinus were performed in the preceding section, the exercise was repeated with the measurements of the Ethmoid sinus. The resultant formulae are:

For the classification of race:

r=levr*0.832+lell*3132-lelr*63.821+lewl*0.079+lewr*3.913-lehl*17.157+lehr*2.903-levlsq*0.01+levrsq*0.071-lellsq*0.779+lewlsq*9.98-lewrsq*0.848+lehlsq*2.992-0.702

For the classification of sex:

g=-evl*1.888+evr*0.804+ell*0.719-elr*0.337-ewl*1.345+ewr*2.222-ehl*0.15-ehr*0.0707+evlsq*0.122-evrsq*0.057-ellsq*0.011+elrsq*0.008+ewlsq*0.056-ewrsq*0.096+ehlsq*0.009+ehrsq*0.012-0.873

- Using the above formula 74% of the skulls being correctly classified according to race and 78% of the crania are correctly classified according to sex. This race and sex classification is entirely based on the measurements obtained by CT scan of the ethmoid sinus.

5.11 SPHENOID SINUS CLASSIFICATIONS

5.11.1 Classification – Race

The classification variables used are the sphenoid volume (left and right), length (left and right), width (left and right) and height (left and right).

The following variables gave the best classification results.

For both race and sex classifications the above mentioned variables (8 variables), their squared values (8 variables) and the product of the corresponding left and right measurements (4 variables) are used.

TABLE 5.77 COEFFICIENTS OF THE SPHENOID CLASSIFICATION FUNCTION FOR RACE

VARIABLE	COEFFICIENT
svl	0.869
svr	0.454
sll	-0.198
slr	-0.381
swl	-0.774
swr	0.318
shl	-0.209
shr	-0.587
svlsq	-0.052
svrsq	-0.028
sllsq	0.004
slrsq	0.006
swlsq	0.033
swrsq	0
shlsq	-0.013
shrsq	0.002
vpr	-0.057
lpr	0.008
wpr	-0.027
hpr	0.032
constant	13.66

1 All the variables ending with an s are squares.

2 The variables ending with pr are right and left crossproducts i.e. svpr = svr*svl, slpr = slr*sll, swpr = swr*swl, shpr = shr*s

5.11.2 Classification – Sex

TABLE 5.78 COEFFICIENTS OF THE SPHENOID CLASSIFICATION FUNCTION FOR SEX

VARIABLE	COEFFICIENT
svl	0.434
svr	-0.431
sll	0.53
slr	-0.199
swl	-0.188
swr	0.371
shl	0.117
shr	0.352
svlsq	-0.028
svrsq	-0.036
sllsq	-0.007
slrsq	0.015
swlsq	0.003
swrsq	-0.008
shlsq	-0.006
shrsq	-0.005
vpr	0.128
lpr	-0.022
wpr	-0.001
hpr	0.002
constant	-9.279

For race, this resulted in 78.8% of the skulls being correctly classified and for sex 75% were correctly classified.

- *Using the same method as for maxillary sinus and ethmoid sinus analysis, the classification formula for the sphenoid sinus resulted in a classification according to race of 78.8% and for sex 75 % of the crania were correctly classified. These classification results were again based entirely on the measurements obtained by CT scan of the sphenoid sinuses of the crania.*

- *Sphenoid (race) formula is:*

  r = 13.66+0.869*svl+0.454*svr-0.198*sll-0.381*slr-0.774* swl+0.318*swr-0.209* shl-0.587*shr-0.052* svlsq-0.028*svrsq+0.004* sllsq+0.006* slrsq+0.033*swlsq+0*swrsq-0.013*shlsq+0.002*shrsq-0.057*vpr+0.008*lpr-0.027*wpr+0.032*hpr

- *Sphenoid (sex) formula is*

  g = -9.279+0.434*svl-0.431*svr+0.53*sll-0.199*slr-0.188*swl+0.371*swr+0.117* shl +0.352*shr-0.028* svlsq-0.036*svrsq-0.007*sllsq+0.015* slrsq+0.003*swlsq-0.008*swrsq-0.006*shlsq-0.005*shrsq+0.128*vpr-0.022*lpr-0.001*wpr+0.002*hpr

5.12 FRONTAL SINUS CLASSIFICATIONS

5.12.1 Classification – Race

The classification variables used are the frontal sinus volume (left and right), frontal sinus length (left and right), frontal sinus width (left and right) and frontal sinus height (left and right).

The following variables gave the best initial classification results.

For both race and sex the above- mentioned variables (8 variables) and the product of the corresponding left and right measurements (4 variables) was used.

TABLE 5.79 COEFFICIENTS OF THE FRONTAL SINUS CLASSIFICATION FUNCTION FOR RACE

VARIABLE	COEFFICIENT
fvl	0.114
fvr	1.096
fll	0.341
flr	0.137
fwl	-0.045
fwr	-0.2
fhl	-0.063
fhr	0.074
vpr	-0.094
lpr	-0.015
wpr	0.002
hpr	0
constant	-0.564

fvpr = fvr*fvl, flpr = flr*fll, fwpr = fwr*fwl, fhpr = fhr*fhl.

5.12.2 Classification – Sex

TABLE 5.80 COEFFICIENTS OF THE FRONTAL SINUS CLASSIFICATION FUNCTION FOR SEX

VARIABLE	COEFFICIENT
fvl	0.496
fvr	-0.563
fll	-0.065
flr	-0.031
fwl	-0.006
fwr	0.12
fhl	-0.109
fhr	0.203
vpr	0.056
lpr	-0.002
wpr	-0.004
hpr	0
constant	-1.671

For race and sex this resulted in 73.6% and 77.4% of the skulls respectively being correctly classified.

- Using the same method as for maxillary sinus and ethmoid sinus analysis, the classification formula for the frontal sinus resulted in a classification according to race of 73.6% and for sex 77.4 % of the crania were correctly classified. These classification results were again based entirely on the measurements obtained by CT scan of the frontal sinuses of the crania.

Frontal (race)

r = -0.564+0.114*fvl+1.096* fvr+0.341*fll+0.137*flr-0.045*fwl-0.2*fwr-0.063 *fhl+0.074 *fhr-0.094*vpr-0.015*lpr+0.002*wpr+0*hpr

Frontal (sex)

g = -1.671+0.496*fvl-0.563* fvr-0.065*fll-0.031*flr-0.006*fwl+0.12*fwr-0.109*fhl+0.203 *fhr+0.056*vpr-0.002*lpr-0.004*wpr+0*hpr

5.13 CLASSIFICATIONS USING ETHMOID, SPHENOID AND FRONTAL SINUS TOGETHER

5.13.1 Combined Classifications

When using the 24 classification variables (volume, length, width, height on the left and right side) for each of the ethmoid, sphenoid frontal sinuses together, 81.6% of the races and 91.8% of the sexes of the skulls were correctly classified. The classification function based on these variables will be referred to as the combined classification function.

TABLE 5.81 COEFFICIENTS OF THE COMBINED CLASSIFICATION FUNCTION FOR RACE

VARIABLE	COEFFICIENT
evl	0.231
evr	0.118
ell	0.015
elr	0.103
ewl	-0.04
ewr	0.137
ehl	-0.031
ehr	-0.029
fvl	-0.2
fvr	0.441
fll	0.115
flr	-0.127
fwl	0.057
fwr	-0.164
fhl	-0.155
fhr	0.23
svl	0.103
svr	0.019
sll	0.108
slr	-0.215
swl	-0.108
swr	0.038
shl	-0.064
shr	0.04
constant	-0.707

TABLE 5.82 COEFFICIENTS OF THE COMBINED CLASSIFICATION FUNCTION FOR SEX

VARIABLE	COEFFICIENT
evl	-0.696
evr	0.373
ell	0.148
elr	-0.013
ewl	0.017
ewr	-0.479
ehl	0.175
ehr	-0.049
fvl	-0.475
fvr	-0.119
fll	0.164
flr	0.085
fwl	0.014
fwr	0.06
fhl	0.166
fhr	-0.251
svl	-0.271
svr	0.099
sll	0.207
slr	-0.058
swl	-0.021
swr	0.025
shl	0.129
shr	-0.036
constant	-2.863

- Using these formulas, when looking at a combination of ethmoid sphenoid and frontal sinus measurements, classification results show that 81.6 % of the crania can be correctly classified for race and 91.8% can be correctly classified for sex.

- **Combined (race) formula**

  r = -0.707+0.231*evl+0.118*evr+0.015*ell +0.103*elr-0.04*ewl+0.137*ewr-0.031*ehl-0.029*ehr-0.2*fvl+0.441*fvr+0.115*fll-0.127*flr+0.057*fwl-0.164*fwr-0.155*fhl+0.23*fhr +0.103*svl+0.019*svr+0.108*sll-0.215*slr-0.108*swl+0.038*swr-0.064*shl+0.04*shr

- **Combined (sex) formula**

  g = -2.863*-0.696*evl+0.373*evr+0.148*ell-0.013*elr+0.017*ewl-0.479*ewr+0.175*ehl-0.049*ehr-0.475*fvl-0.119*fvr+0.164*fll+0.085 *flr+0.014*fwl+0.06* fwr+0.166*fhl -0.251*fhr-0.271*svl+0.099*svr+0.207*sll-0.058*slr-0.021*swl+0.025*swr +0.129*shl -0.036*shr

5.14. SKULL CLASSIFICATION USING MAXILLARY SINUS AND ETHMOID SINUS MEASUREMENTS

5.14.1 Classification – Race

The results presented below are the result of maxillary and ethmoid combined classification analysis.

Race: The weights and variables of the classification function with the highest percentage of correct race classifications are shown in the table below. Comment: Total distance across the sinuses (td) was included as a variable for race.

TABLE 5.83 BEST CLASSIFICATION FUNCTION FOR RACE

VARIABLE	WEIGHT
mwr	-0.009
mwl	0.14
mlr	-0.061
mll	0.207
mhr	-0.005
mhl	0.152
evl	-0.024
evr	0.204
ell	0.029
elr	0.106
ewl	-0.158
ewr	-0.119
ehl	-0.066
ehr	0.004
td	-0.067
constant	-8.056

- This above function classifies the race of 95.9% (47 out of 49) of the skulls correctly for race.
- Maxillary, ethmoid and td (race)

  r = -8.056-0.009*mwr+0.14*mwl-0.061*mlr+0.207*mll-0.005*mhr+0.152*mhl-0.024* evl+0.204*evr+0.029*ell+0.106*elr-0.158*ewl-0.119*ewr-0.066*ehl+0.004*ehr-0.067*td

5.14.2 Classification – Sex

The weights and variables of the classification function with the highest percentage of correct sex classifications are shown in the table below. Nasal cavity width (ncw) was included as a variable for sex.

TABLE 5.84 BEST CLASSIFICATION FUNCTION FOR SEX

VARIABLE	WEIGHT
ncw	.172
mlr	-2.400
mll	1.312
mlrs	.035
mlls	-.020
mhrs	0.0002
mhls	.001
mvl	0.00005
mvr	-0.00003
evl	.347
evr	-.192
ell	-.116
ehl	-.055
ehr	.091
constant	13.823

The above function classifies the sex of 87.8% (43 out of 49) of the skulls correctly.

When considering the race and sex classifications together, 83.7% (41 out of 49) of the skulls were correctly classified.

- Maxillary, ethmoid and ncw (sex) g = 13.823+0.172*ncw-2.4*mlr+1.312*mll+0.035*mlrs-0.02*mlls+0.0002*mhrs+ 0.001*mhls+ 0.00005* mvl-0.00003*mvr+0.347*evl-0.192*evr-0.116*ell- 0.055*ehl +0.091*ehr

- Using the above formula, when looking at a combination of maxillary and ethmoid sinus measurements (maxillary ethmoid and nasal cavity width), classification results show that 87.8% can be correctly classified for sex.

5.15 SUMMARY

Correct classification percentages attained by classification formulae

TABLE 5.85 CORRECT CLASSIFICATION PERCENTAGES

	MAXILLARY	ETHMOID	SPHENOID	FRONTAL	COMBINED	MAXILLARY, ETHMOID
Race	90.6	74	78.8	73.6	81.6	95.9
Sex	84.9	78	75	77.4	91.8	87.8

The classifications with the highest correct percentages are those using maxillary and ethmoid (for race) and using combined measurements (for sex).

CHAPTER 6: DISCUSSION

One of the most interesting and challenging aspects of forensic medicine is identification, notably the identification of crania. Forensic pathologists and anthropologists, when asked to identify skeletal material, initially focus on age, biological sex and geographic ancestry or racial grouping. These highly significant determinations are important in the process of identification. It is necessary to have as accurate as possible determination of age, sex and racial grouping. Therefore, research such as this, which is aimed at enhancing the accuracy of any of these areas, is of value to the fields of forensic anthropology and forensic pathology.

The results of this research yield new findings that show significant differences in the human paranasal sinuses between differing race and sex groups; namely Zulus and Europeans. It is an anatomical study encompassing all the paranasal sinus measurements - both volumes and linear measurements have been analysed within this framework and all within the field of forensic medicine. It is the goal of this research to make a contribution to the field of forensic medicine, in particular to the realm of human identification research.

Historically, radiology has been limited in its applications to forensic medicine in the field of identification. Visual inspection, anatomic measurement, and precise measurement of bone dimensions often exceed radiologic contribution, particularly where identification of skeletal remains is required. By using advanced computed tomography over older radiological methods, a very successful classification of two race groups, namely Zulus and Europeans, for race and sex was achieved. In the fields of forensic medicine and anthropology, it may be possible to find a role for paranasal sinus measurements in identifying human remains. This research is specific to the European and Zulu male and female populations of Southern Africa

This cadaver study was conducted on human crania from the renowned Raymond Dart Collection of Human Crania in Johannesburg, South Africa. A selection of live patient scans were analysed to further broaden the spectrum of the study. Original classification formulas were obtained to show how it is possible to classify a cranium of unknown origin into a race and/or sex group. The significant classification results obtained in this research improve on this author’s previous original published research on the maxillary sinus volumes and their role in forensic race identification (Fernandes, 2004).

The aim of this research was to investigate the role of paranasal sinus dimensions in human identification. Europeans and Zulu male and female crania were analysed in terms of paranasal sinus measurements and volumes. The role of the human paranasal sinuses in our two groups in human identification has been established by the discovery of significant race and sex variations in the paranasal sinuses. This study provides, to date, the best classification figures for race and sex classification by using all the paranasal sinus measurements and searching for the ideal combination to be able to predict race and sex. This author was the first author to establish a possible role for the paranasal sinuses in the identification of a cranium of unknown origin (Fernandes, 2004). Now a certain role is established and a new combination of sinus measurements has been discovered with an significant 95.9 % correct classification for race /race group and 91.8 % correct classification figure for sex.

Traditionally, racial identification of the cranium involves a comparative analysis of the shape of the cranium, the ramus of the mandible, the chin, the nasal aperture, the nasal bones, the cranial sutures, the palatal shape, the degree of prognathism, the zygomaxillary suture, the zygomas and the dentition (Adelson 1974). Fernandes (2004) discovered that persons of European descent had larger maxillary antra than did those of Zulu decent (Fernandes 2004). Overall European maxillary sinuses were 48% larger in volume than Zulu maxillary sinuses with the European male maxillary sinuses being 62% bigger than Zulu male maxillary sinuses (Fernandes2004). This significant variation gave rise to the idea to analyze, in a similar manner, the rest of the human paranasal sinuses in these race and sex groups. New methods obtained in this research aim to assist in accurately determining whether a cranium of unknown origin can be assigned to one or other race or sex group. The predictive role of the maxillary sinus in human identification is assessed again and analyzed in combination with all the human paranasal sinus measurements and volumes. It is the goal of this forensic research to improve on the existing classification figures found in the previous research and in so doing add new ideas, methodology and form the basis for new techniques in the realm of human forensic identification. In so doing, we find new tools to add to the armamentarium of the forensic pathologist and anthropologist who is asked to identify skeletal remains.

This research may provide a basis for other studies in other known population groups and thus finds it’s place in human identification studies, in particular it may assist with identifying crania of unknown race group or sex.

This research focuses on determining ancestry and biological sex from crania in the European and Zulu populations of southern Africa. The forensic anthropologist or pathologist, when confronted with skeletal remains, must create a biological profile through the analysis of the remains. The basic components of a biological profile are age, sex, height, and ancestry. Of these four characteristics, ancestry is perhaps the most difficult to assess.

In terms of determining geographical ancestry or race group (further detailed in Chapter 2 section 2.2), the skull is considered the most useful part of the skeleton to use for assessment of ancestry (Howells 1973; Rhine 1993). There are two widely used methods for assessing ancestry; metric and non-metric (They are discussed in detail with reference to authors in chapter 2, section 2.2). This study contributes to the metric methods. In the most popular metric method, the FORDISC 3.0 (Jantz and Ousley 2005), the forensic expert takes thirty-six different measurements of a skull. These measurements are then put into the program, which calculates matrices and does a linear discriminate analysis. The skull is then classified into a population group. The program calculates the probability that the skull belongs to a particular population.

Classification using Fordisc has been recently criticised for its numerous problems. In 2012 research presented at the 81st Annual Meeting of the American Association of Physical Anthropologists concluded that Fordisc ancestry determination was not always consistent, and the programs' recommended acceptance criteria did not separate correct and incorrect determinations. The authors concluded that the program does not perform to expectations and should be used with caution. A number of researchers have applied the program to specimens of known ancestry and concluded from the high numbers of incorrect attributions that the program is flawed (Kosiba 2000; Leathers et al. 2002; Williams et al. 2005).

Therefore our research can contribute to metric methods of ancestry or race group identification. Its limitations will be different from the Fordisc 3.0's limitations and its method of measurement i.e. CT scanning, is known for it's accuracy. Perhaps its value may lie in introducing these measurements into the Fordisc 3.0 Program for different populations. Ultimately, it has been seen that the paranasal sinus measurements have a role in ancestry determination based on our very successful classification figures for ancestry. Overall, the best figure obtained from classification according to race -in this study -was for a combination of maxillary, ethmoid and total distance across the sinuses. This yielded a result of 95.9%.

These are possibly the most successful classification figures to date for classification according to race using the measurements of the paranasal sinuses.

Historically, other authors' research on race classification are detailed further in Chapter 2 section 2 under the section, Metric and non metric methods of determining ancestry. Perhaps the paranasal sinus measurements may be used in combination with other features of the skull, such as mandibular traits, to determine ancestry.

For sex, an excellent result was obtained of 91.8% by combining ethmoid, sphenoid and frontal paranasal sinus measurements. This allowed for the correct classification of a cranium according to sex in this European and Zulu population. These results obtained for sex classification are very successful and based on paranasal sinus measurements.

Fernandes 2004 was the first author to describe the variation in maxillary sinus dimensions and volumes and to suggest a possible role in ancestry and gender determination. This 2004 study was a pilot study and subsequently other authors investigated the role of the maxillary sinus measurements in ancestry and sex determinations. In the subsequent study by Sharma, et al (2014) "Measurements of Maxillary Sinus Volume and Dimensions using Computed Tomography Scan for Sex Determination", 65% of Indian males and 69 % of Indian females were correctly sexed (Sharma et al 2014). Our figures were superior. In another current study; "Sex Determination using the Maxillary Sinus" by Kanthem, et al (2015), it was confirmed that sex determination using height, width, length and volume of the maxillary sinus showed statistically significant results. Attia et al, (2012) were able to achieve a 71.8% classification for males and 67.6 % classification for females using the maxillary sinus measurements in an Arab population (Attia et al, 2012). Teke et al, (2007) obtained 69,3% for Turkish males and 64% for females using maxillary sinus measurements. The Kurdish study undertaken by Ahmed et al, (2015) using CT images to analyze maxillary sinus measurements as a forensic tool for sexual and racial detection of the Kurdish population, was able to confirm the findings of Fernandes (2004) and that the diameters of the maxillary sinus can be used successfully as an adjunct tool for racial and sex determination (Ahmed et al, 2015). All these above mentioned studies support the original findings of this author. These studies further show that the sinuses may hold extreme value for forensic identification.

Other authors and means of assessing sex and ancestry are detailed further in Chapter 2.2. Our method compares extremely favorably because it overcomes much of the limitations of non-metric methods such as subjectivity, error in measurements; and it can add to the existing metric methods used today. It is recommended that the paranasal sinus measurements now be used in conjunction with existing methods in human identification when establishing race and sex groups. It is further recommended that a database of other geographical race group's measurements be established.

In analysing the results, two approaches were undertaken. The first analysis in Part 1 of the results, comprised of an analysis of the volumes and the measurements of width, height and length of the maxillary, ethmoid, sphenoid and frontal sinuses of European and Zulu, male and female sinuses.

Part 2 of the results provided a more detailed analysis using SPSS. In this section, individual sinus sides were additionally analysed to look for possible differences between the sinuses of European and Zulu males and females. This idea of looking at individual sinus sides was novel, it provided greater statistical detail for analysis, and it was of good value in determining if sidedness is significant and this was important to do if looking for possible anatomical variation. Paranasal sinuses may contribute to the shape of the midface and in terms of symmetry, it could be significant.

In assessing the results for differences between left and right measurements, it was found that for maxillary and ethmoid sinus measurements there were no significant differences between left and right measurements as described in table 5.37. This gave rise to the very important idea that if searching for an race and/or sex predictor, that the maxillary and ethmoid sinuses would be the most suitable to use. They are somewhat symmetrical. Now the possibility to classify a cranium into an race or sex group using the volumes and measurements of the maxillary and ethmoid sinuses would likely be possible.

For frontal, significant differences exist between the left and right sides, which correlates with literature supporting anatomic variability in the frontal sinuses.

An analysis of the volume results for each sinus and the measurements for each sinus allow for us to document unexpected differences between the differing race and sex groups. The results of the volumetric and measurement studies of the four sinuses will be demonstrated below in Table 6.1. Table 6.1 shows volumes and measurements of maxillary, ethmoid, sphenoid and frontal sinuses in the dried crania below.

Table 6.1 RACE AND SEX MEAN VOLUME, WIDTH, LENGTH AND HEIGHT MEASUREMENTS, RACE/SEX INTERACTION AND SIGNIFICANCE.

	Race	*Race*	*Race*	*Sex*	*Sex*	*Sex*	*Race Sex**
Volume Mean (cm3)	E	Z	p value Sig*	M	F	p value Sig*	
Maxillary	16.73	10.76	<0.0001*	14.96	12.53	0.0141*	n/s
Ethmoid	4.93	3.62	0.0228*	4.22	4.32	n/s	n/s
Sphenoid	3.70	3.58	n/s	3.55	3.73	n/s	0.0392*
Frontal	3.65	3.50	n/s	4.18	2.97	n/s	n/s
Width (mm)							
Maxillary	25.44	20.87	<0.0001*	23.36	22.94	n/s	0.0384*
Ethmoid	12.31	11.77	n/s	12.28	11.81	n/s	n/s
Sphenoid	15.88	16.44	n/s	15.98	16.34	n/s	n/s
Frontal	25.32	25.76	n/s	27.75	23.34	n/s	n/s
Length (mm)							
Maxillary	39.80	34.63	<0.0001*	38.14	36.29	n/s	n/s
Ethmoid	28.73	25.06	0.0284*	26.01	27.78	n/s	n/s
Sphenoid	16.76	16.63	n/s	15.93	17.46	n/s	0.0027*
Frontal	9.16	7.61	n/s	8.87	7.9	n/s	n/s
Height (mm)							
Maxillary	36.44	31.66	0.0002*	35.11	32.98	n/s	n/s
Ethmoid	21.60	19.95	n/s	20.63	20.91	n/s	n/s
Sphenoid	21.82	21.90	n/s	22.46	21.25	n/s	n/s

*n/s not significant *significance*

VOLUMES

In analysing the maxillary sinus volumes, it was revealed that European crania had larger maxillary sinuses than Zulu crania and that male crania overall were larger than female crania. Race was highly significant $p<0.001 (p=0.000)$. Sex was also significant with male sinuses having a larger volume than female sinuses $p<0.05$ ($p=0.002$). Maxillary sinus volumes are well known to be important in dental implant and in upper jaw surgery. In dental implant surgery, the relevance is to how much grafting of the sinus floor is required in order to secure a dental implant in the upper jaw.

European crania had larger ethmoid sinus volumes than Zulu crania and that male crania had smaller ethmoid volumes than females. European females had the largest sinuses. Race was significant, with European sinuses being larger in volume than Zulu sinuses ($p = 0.0228$). Ethmoidal volume may have a bearing on endoscopic sinus surgery.

Volumetric analysis of the sphenoid sinuses revealed no significance for race or sex. The only significant factor identified was race sex interaction ($p=0.0392$).

Volumetric analysis of the frontal sinuses revealed no significance for race or sex or race sex interaction.

The next step was to analyse the measurements of width, height and length taken of the maxillary, ethmoid, sphenoid and frontal sinuses. These measurements are important in the overall assessment of anatomical variation according to race and sex.

Race was found to be very significant with European maxillary sinus widths being much larger than Zulu maxillary sinus widths ($p < 0.0001$). Race and sex interaction was found to be significant ($p = 0.0384$) with European female maxillary sinuses being larger in width than European male maxillary sinuses and the Zulu male sinus widths were found to be larger than Zulu female sinus widths and this difference was statistically significant.

WIDTHS

Race, sex and race sex interaction for the ethmoid sinus widths were not significant and the sinus appears fairly uniform across the race and sex groups.

Sphenoid width analysis revealed that neither race, sex, nor race sex interaction was significant.

The statistical analysis of the frontal sinus width measurements showed neither race, sex nor race sex interaction was significant.

LENGTHS

The next analysis was a length analysis of the four paranasal sinuses. Again, a variation in length between the race and sex groups may contribute to a variation in anatomy between the European and Zulu male and female categories.

The maxillary sinuses demonstrated significant differences in length between the races. Europeans were found to have greater average maxillary sinus lengths than Zulu's. Race was very significant (p=0.000) for length. Sex was not.

Ethmoid length analysis revealed significant differences between the races with Europeans having longer ethmoid sinus lengths. Race was significant (p=0.0284).

Sphenoid sinus length analysis did not identify significant differences between the races and no significance for sex was found. However race sex interaction was deemed significant (p=0.0027) because European males and Zulu females both had smaller sphenoid sinus lengths than their counterparts within their respective races and these differences were statistically different from each other.

The length analysis of the frontal sinuses exhibited no significance in terms of race, sex or race sex interaction. This may be attributed to the variation and uniqueness in frontal sinus dimensions in individuals.

HEIGHTS

The height analysis of the maxillary sinus showed that Europeans had on average larger maxillary sinus heights. Only race was identified to be significant (p=0.0002)

Ethmoid sinus heights demonstrate no significance in terms of race, sex or race sex interaction. Sphenoid sinus height analysis follows much the same as ethmoid sinus height analysis with no significance for race, sex or race sex interaction.

Frontal sinus heights analysis revealed that sex was significant (p=0.012) with males having greater sinus heights.

In Part Two of the paranasal sinus results analysis, i.e. of volumes, widths, lengths and heights, it was found that all measurements of left and right paranasal sinus sides fully corroborated the findings in Part One of the results. This was important as Part One of the results was analysed using SAS and Part Two of the results was a more detailed SPSS analysis of each individual maxillary, ethmoid, sphenoid and frontal paranasal sinus side. As mentioned prior, looking at individual sinus sides provided greater detail to the research and it was found that for maxillary and ethmoid sinus measurements there were no significant differences between left and right measurements, but the sphenoid and frontal sinuses exhibited much variation. In particular, the uniqueness of the frontal sinus that has proved valuable in personal identification was evident as for frontal sinus measurements significant differences exist. Of interest, it was noted that right frontal sinus heights for sex were highly significant ($p=0.002$) and this anatomical variation in side may hold significant clinical significance in terms of surgery in the region. In essence, in Part One, all race, sex and race sex significances were corroborated in Part Two.

The analysis of nasal cavity width (ncw) and the total distance (td) across the sinuses was undertaken as part of this anatomical assessment. This analysis revealed that nasal cavity width measurements are not significant for race. European and Zulu crania do not exhibit much variability between each other in terms of nasal cavity width. Significance exists between nasal cavity width between sexes with males having larger nasal cavities than females. Race sex interaction was not found to be significant for nasal cavity width.

The measurements analysed for total distance across the sinuses are significant for race, Europeans have a larger total distance than Zulus. Sex is not significant with regards to total distance across the sinuses. Race and sex interaction was found to be significant with European males being slightly smaller than European females, whilst Zulu males were greater than Zulu females.

The importance of analysing the live patient CT scans of the sinuses was to see if the results could, to some degree, replicate the measurements from the dried crania. If one is looking to classify a cranium according to the dimensions of the sinuses, then being able to replicate the work is important. Analysing and identifying anatomical variations and similarities is of interest. Do these variations exist and persist within the sinus measurements of the same race group or race? In the same manner, within the sex group, do the variations or similarities in measurements persist? Can they be used for race or sex classification and applied to human identification studies? From the results obtained in this study, it seems so. Also, bearing in mind that some of the dried crania are many years old, it was an idea to analyse these current day patients CT scans. This, additionally, was to consider the possibility of any influence of factors that may have had a bearing over time such as the possibility of skull size change due to environment, diet etc.

When analysing the results of the live patient analysis it is noted that there are many like findings in the dimensions and measurements of the paranasal sinuses in the live patients CT analysis and in the dried crania from the Dart collection. This is a significant finding.

Never before have the findings of dried crania been compared to live patients in terms of paranasal sinus measurements and therefore findings in the cadaver study are validated by corroborative live patient findings. For the maxillary sinus analysis of measurements of volumes, widths, lengths and heights of the live patients, it was found that all maxillary measurements were highly significant for race. This was identical to the findings of the dried crania study. Analysis of sex measurements in the live patient analysis showed significance for sex as far as volumes and lengths and this was the same in the live patients as the dried crania. Maxillary volumes, lengths and heights were not significant for measurements for race sex interaction. Again, the same findings in the dried crania but variation in race sex interaction existed in the widths, where live patients were not significant for widths for race sex interaction. Overall the maxillary sinus analysis of paranasal sinus measurements in the live patients showed close conformity with the results of the dried crania study of paranasal sinus measurements. This indicates that the maxillary sinus has role in forensic race identification of crania.

In the ethmoid complex, the live patient findings mirrored the dried crania findings in terms of volume for race being significant; widths, lengths and heights being not significant in both, and for race sex interaction in the ethmoidal sinuses all parameters were not significant in both live patients and the dried crania. This indicates that the measurements of the ethmoid sinuses may also hold value for forensic race identification of crania.

The sphenoid sinus results in the live patient analysis were more difficult to corroborate with the findings of the dried crania study. Overall there was 58 %

corroboration between the live patient findings and the dried crania. This indicates the variability in sphenoid sinus and its usefulness in forensic race identification is therefore limited.

The frontal sinuses showed a 92 % likeness between the findings of the live patients and the dried crania. Essentially nearly all findings were non significant. In terms of race; volumes, widths and heights all were not significant in both the live patient and dried crania study. In respect of sex; volumes, widths and lengths were not significant for both groups and for race sex interaction all the variables were not significant for both the live patients and the dried crania. These findings identify the uniqueness of the frontal sinus and highlight its usefulness in personal identification rather than in predicting race or sex in crania of unknown origin.

Importantly, the dried crania paranasal sinus study and the above corroborations from the live patient findings, suggests uniformity in the shape and dimensions of the maxillary and ethmoid sinuses within the specific race and sex groups. Herewith lies the key to being able to classify a cranium according to race or sex in a measurable, less subjective way. This paves the way in human identification studies for forensic identification according to race and sex, certainly in this study.

Now that the maxillary, ethmoid, sphenoid and frontal sinus volumes and measurements of length, width and height were statistically analysed to look for variations between the differing race and sex groups, a search for a method to predict race group or sex was undertaken. Discriminant analysis was performed. Race, sex and race sex interaction was assessed for all the sinus measurements.

The next aspect of the research was an extension of the research to create classification formulae. This analysis involved additional craniometrical measurements and allowed for the creation of new formulae to predict raceity and sex from an unknown cranium.

The results of the classification formulae were significant. The original classification formulae created in this original study yielded perhaps the best classification figures in the world to date, when using the dimensions of the paranasal sinuses to classify a cranium into either of the race or sex groups in this study.

Table 5.85 details the percentage correct classifications obtained using the new classification formulae created in this study. The formulae to be used are detailed in Part 4 of the results chapter. The important results are detailed below. The very best results obtained was the race classification figure of 95.9% and the sex classification of 91.8%. Detailed below is a summary of how they were obtained and which relevant measurements were used to enhance the classifications.

For the maxillary sinus 90.6% of the crania were correctly classified according to race.

For the maxillary sinus 84.9% of the crania were correctly classified according to sex.

For the ethmoid sinus 74% of the crania were correctly classified according to race.

For the ethmoid sinus 78% of the crania were correctly classified according to sex

For the sphenoid sinus 78.8 % of the crania were correctly classified according to race.

For the sphenoid sinus 75% of the crania were correctly classified according to sex

For the frontal sinus 73.6% of the crania were correctly classified according to race.

For the frontal sinus 77.4% of the crania were correctly classified according to sex.

For the combination of ethmoid, sphenoid and frontal sinuses, 81.6 % of the crania were correctly classified according to race.

For the combination of ethmoid, sphenoid and frontal sinuses, an excellent 91.8% of the crania were correctly classified according to sex.

From a combination of maxillary and ethmoid sinuses:

Maxillary, ethmoid and total distance across the sinuses yielded an significant 95.9% classification for race.

For sex, a combination of maxillary, ethmoid and nasal cavity width measurements yielded a very good 87.8% classification.

The above results are significant for race and sex classification in the European and Zulu population. Overall, the best figure obtained from classification according to race was for a combination of maxillary, ethmoid and total distance across the sinuses. This yielded an significant result of 95.9%. These appear to be the worlds best classification figures to date for classification according to race using the measurements of the paranasal sinuses.

For sex, an excellent result was obtained of 91.8% by combining ethmoid, sphenoid and frontal paranasal sinus measurements. This allowed for the correct classification of a cranium according to sex in this European and Zulu population. Again, these seem to be the best classification figures obtained for sex classification in the world to date by use of the paranasal sinus measurements.

In forensic medicine, the establishment of race and sex is paramount in the identification process. Forensic medicine and anthropology can now be certain that the paranasal sinus measurements do and will play an important role in identifying human remains.

The concept of the role of the maxillary sinuses in human identification was first discovered by this author in a first published study entitled "Forensic Race Identification of Crania. The Role of the Maxillary Sinus-A new Approach" (Fernandes, 2004). Many studies have replicated and validated this research looking for ways to predict race and sex groups in different populations. Not many studies achieved such significant classification figures as the 2004 publication by Fernandes. However, many of the subsequent authors studies were done on CT scans already taken for medical reasons and extraneous variables could well exist. These research studies clearly confirm the findings of this author in establishing the significance of maxillary sinus measurements in determining sex or race and thus their use as a forensic tool in human identification. In the study by Sharma, et al (2014) "Measurements of Maxillary Sinus Volume and Dimensions using Computed Tomography Scan for Sex Determination", 65% of Indian males and 69 % of Indian females were correctly sexed. In another current study; "Sex Determination using the Maxillary Sinus" by Kanthem, et al (2015), it was confirmed that sex determination using height, width, length and volume of the maxillary sinus showed statistically significant results. Attia et al, (2012) were able to achieve a 71.8% classification for males and 67.6 % classification for females using the maxillary sinus measurements in an Arab population. Teke et al, (2007) obtained 69.3% for Turkish males and 64% for females using maxillary sinus measurements. The Kurdish study undertaken by Ahmed et al, (2015) using CT images to analyse maxillary sinus measurements as a forensic tool for sexual and racial detection of the Kurdish population, was able to confirm the findings of Fernandes

(2004) and that the diameters of the maxillary sinus can be used successfully as an adjunct tool for racial and sex determination.

All these above mentioned studies support the original findings of this author.

This author's new idea of analysing measurements and volumes of all the paranasal sinuses in search of an even better way to classify a cranium according to race and sex was borne as an extension of the original idea and her work on the maxillary sinus. It is this author's fundamental belief that the sinuses hold extreme value for forensic identification.

The results of this study show that the anatomical variability exists in the paranasal sinuses between different race groups and sexes. Whist all paranasal sinus volumes and measurements were analysed in this research study, the very best combination of classifiable measurements were discovered and are being put forward as a strong tool in human forensic identification studies. The significant sex classification figure of 91.8% by combining ethmoid, sphenoid and frontal paranasal sinus measurements, is the best seen to date and a first discovery for using a combination of the sinuses.

The significant race classification figure of 95.9 % is by far the highest classification figure to date for classification according to race. This was done using the measurements of maxillary, ethmoid and total distance across the sinuses. All this was done using the measurements of the paranasal sinuses in a European and Zulu, male and female population.

The above results are very successful. By taking the abovementioned measurementsand utilising the formulas created in this research, a cranium of either European or Zulu origin can be correctly classified with 95.9% accuracy for race group and a 91.8% for sex.

Applications of these findings hold value in forensic identification where forensic pathologists may be asked to identify the race group and sex of a cranium of unknown origin. Often the cranium is the last remaining part to be found is and is fairly resistant to decomposition. This means that the sinuses are often protected within the bony skull and are more readily available for performing race and sex analysis on. Herewith we now have a measurable way of determining race and sex and this classification is based on actual measurements and therefore eliminates some of the subjectivity anatomical variation is also of value in orbital decompression surgery and anterior skull base surgery. If the sinuses are smaller as found in the Zulus, orbital damage and CSF leaks are more likely to occur. Sphenoidal volumes and variations are of significance in endoscopic transphenoidal surgery. Frontal sinus volumes and variations are of importance in frontal sinus obliteration surgery and reconstructive surgery.

In conclusion, this research study has firmly established a role for the paranasal sinuses in human forensic identification, with highly successful classification results for correctly classifying a cranium of Zulu or European origin into it's sex or race group. A method is provided for use in the field and it can be suggested that with radiological and statistical support, this method can be used as a tool for forensic human identification. In time it is hoped that other authors will replicate and add to the body of work so that a sinus database may be created to assist in identifying crania of unknown origin within a region.

Paranasal sinuses exhibit both race and sex anatomical variations. From the conformity of the maxillary and ethmoid sinuses to the uniqueness of the frontal sinus, it is a complex field. This research establishes the role of the paranasal sinuses in human forensic identification and it's existence beyond the author's first discovery of the role of the maxillary sinus. A combination approach of measurements of the paranasal sinuses certainly appears to hold the key to human identification. A new discovery by way of combining paranasal sinus measurements for use in race and sex classification of crania has been discovered. At 95.9% correct race classification and 91.8% correct classification for sex using new paranasal sinus measurements in combination, this research has had an extremely successful outcome.

CHAPTER 6: REFERENCES

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