Analysis of Frontal and Maxillary Sinus Dimensions by Computed Tomography scans for Sex Determination

THESIS

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Abstract

Sex identification is a crucial step in the identification process of unknown human remains, and is mandated by law and complies with social norms. This task becomes increasingly difficult with remains that have badly decomposed, or have been distorted by any natural, or man-made disasters. Thus, methods of identification must be established for when incomplete, or damaged remains are found. The goal of this study was to apply previously established methods of sex estimation utilizing the sinus’ to test their accuracy on a new sample.

A retrospective study was performed on previously acquired CT scans within the IBRC database. The study was designed to measure volume of the frontal and maxillary sinus, as well as the medial-lateral, superior-inferior, and anterior-posterior dimensions of the maxillary sinus, in an attempt to replicate two previously established methods of sex identification in an effort to identify a preferential sinus for sex identification. 57 subjects (30 male, 27 female) were identified and their CT scans were used to obtain measurements utilizing Osirix Software.

Intraobserver error was first quantified within the current study. A statistically significant difference (p<0.0001) was found between frontal sinus volume when measured by the same observer, which suggests measurement error, and a need for cautionary interpretation or application of results. A nonsignificant statistical difference
was found between the male and female sample frontal sinus volumes, which determined this parameter to be unfit for use in sex determination due to the lack of sexual dimorphism. This was further supported with the attempted replication of previously established frontal sinus formulas by Michel et al. (2015) which yielded a considerably low overall accuracy rate of 59.6%.

All maxillary sinus parameters were determined to have nonsignificant statistical differences ($p > 0.05$) between the right and left, suggesting that utilizing both sides for future studies may not be necessary. Four measurements were used to determine if sexual dimorphism exists in the maxillary sinus with varying results: superior-inferior linear length ($p = 0.003$), medial-lateral linear length ($p = 0.048$), anterior-posterior linear length ($p = 0.047$), and volume ($p = 0.069$). Despite three of the parameters indicating statistical significance, only the superior-inferior dimension between the male and female samples shows practical relevance. The overall weak relationships between sexes indicate a general lack of sexual dimorphism of parameters used in the previously established maxillary sinus formulae developed by Rai et al. (2016). Furthermore, these formulas resulted in variable sex identification accuracy, with the best results obtained using the formula for the right maxillary sinus only. This produced sex prediction with an accuracy rate of only 60.00% within the male sample, and 62.96% in the female sample.

This study determined that the right maxillary sinus formula provided the best accuracy results within the given sample, however these results are still lower than ideal accuracy rates. Given the low accuracy rates of these methods of sex identification, and
the lack of sexual dimorphism between the chosen parameters, the current study does not support the use of either method in sex determination.
Dedication

This document is dedicated to my family, for being so supportive through a tough few years.

As well as my pet hedgehog, Meatball, may he rest in peace.

I would first like to acknowledge my thesis advisor, Dr. John Bolte IV, for helping guide me through many obstacles these last two years, and being an ear to talk to whether it was school or life troubles. Secondly, I would like to acknowledge my committee, Dr. John Bolte IV, and Dr. Amanda Agnew, for taking on a student without any experience in research. They’ve helped open my eyes to the world of research before the beginning of my professional school experience, where I will need to dedicate myself to research projects in order to accomplish my future goals of earning a spot in a pharmacy residency program. I would also like to acknowledge the Injury Biomechanics Research Center for allowing me to use their equipment, software, and CT database, without which I would not have been able to conduct this study. I would like to acknowledge Nicole Crowe, for assistance with SPSS software, data analysis, and for keeping me company in lab during many late nights of data collection, and studying. Finally, I would like to acknowledge Dr. Pierson, whom unintentionally became a meaningful mentor to me throughout this program, and inspired a much unanticipated love for the area of neuroanatomy, which I hope to continue to use in my future endeavors.
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Chapter 1: Introduction

Personal identification is often observed as a need for unknown remains after natural disasters, such as tsunamis, earthquakes, floods, and landslides, and is defined as the process of establishing the identification of an individual. Personal identification may also be needed in the case of man-made disasters which consist of terrorist attacks, mass murders, or bomb blasts, as well as when a body is purposely dismembered in a manner that may conceal the identification (Tiwari et al. 2016). The process of identifying an individual from decomposing body parts, or skeletal remnants is one of the most difficult aspects of forensic medicine regardless of the rapid progress in various diagnostic methods (Ahmed et al. 2015; Sharma et al. 2014). Sex identification, as well as age, and ethnicity play important roles in identifying an unknown individual. Sex identification specifically remains a crucial aspect of identifying unknown human remains in forensic medicine, particularly when it is not possible to obtain whole skeletons or remains for analysis (Hamed, El-Badrawy, and Fattah 2014; Kiran, Ramaswamy, and Khaitan 2014). Since forensic anthropologists frequently receive incomplete skeletons, and skeletal remains can be preserved over centuries, skeletal-based identification is critical, and an area where alternate methods of identification should be researched for sex estimation (Akhlaghi et al. 2016; Sharma et al. 2014).
If an investigator is able to accurately predict the sex of unknown skeletal remains, it would further focus the search of missing person’s files, as it narrows down the field of possible identifications to \( \frac{1}{2} \) of the sample (Goyal et al. 2013; Mathur et al. 2013; Rai et al. 2016). This can vastly shorten the work of an investigator by narrowing the amount of antemortem records to be retrieved for comparison with the unknown remains (Goyal et al. 2013). Although the identification of human remains after a death is a difficult forensic procedure, it is mandated in order to comply with the law and social norms as there are often consequences, usually financial, that require identification to be established before verdicts are passed (Amin and Hassan 2012; Chandra et al. 2014; Rai et al. 2016; Teke et al. 2006).

There are vast techniques that may be applied in an attempt to identify unknown human remains including fingerprint analysis, deoxyribonucleic acid matching, anthropological methods, and radiological methods (Kanthem et al. 2015). Other parameters have been used specifically in an attempt to identify the sex of an individual, these include various parameters such as craniofacial height, mastoid height, bicondylar width, mandibular width, pelvis, skull, long bones with assessment of epiphysis and metaphysis, the distance between basion and prosthion, the circumference of the head, length of the supraorbital ridge, mastoid process, nasal aperture mandibular ramus, shape and length of the palate, circumference of occipital condyle, size of teeth, length and height of head, distance between the basion and nasion, the height of the mandibular symphysis, foramen magnum, sphenoid sinus, sella turcica, mastoid air cells, as well as
the frontal and maxillary sinuses (Goyal et al. 2013; Kotrashetti et al. 2014; Mathur et al. 2013; Teke et al. 2006; Rai et al. 2016) Out of these possibilities, the skull, pelvis and foramen are considered to be the most useful in terms of radiologically determining the sex of an unknown individual by applying certain formulas to the acquired dimensions (Chandra et al. 2014).

Fingerprinting is a widely-accepted practice for not only accurately identifying a remains’ sex, but their identity as well. However, there are cases in which the collection of a fingerprint has become difficult or impossible due to remains being poorly decomposed, fragmented, or charred (Tiwari et al. 2016). DNA analysis is also widely-accepted; however, this method can be very time consuming and expensive (Mathur et al. 2013). In these circumstances, it is important to have research exploring the accuracy of other methods of identifying the sex of an individual, in hopes of leading to the actual identification of the unknown remains.

The act of identifying a postmortem individual as a forensic procedure becomes increasingly difficult when certain postmortem changes have occurred. These changes could include decomposition and skeletonization which occur due to environmental factors including but not limited to humidity, temperature, and exposure to microorganisms (Rai et al. 2016). Occasionally extreme postmortem changes due to explosions, warfare, aircraft crashes, and other mass disasters occur which lead to the task of determining the sex of remains, and their identification increasingly difficult (Hamed, El-Badrawy, and Fattah 2014; Kanthem et al. 2015; Tambawala et al. 2016;
Uthman et al. 2011). These extreme post mortem changes may also lead to typical identification methods previously mentioned to remain inconclusive (Teke et al. 2006).

When extreme post mortem changes lead to remains being burned or skeletonized, it becomes necessary to use forensic dental and anthropological analysis as a means to identify the individual (Kotrashetti et al. 2014). These methods are extremely helpful in identifying remains as bones are the second to last aspect of a body to perish after death, and enamel of teeth are the last (Uthman et al. 2011). Skeletal remains conventionally used for sex identification (pelvis, long bones, and skull) are commonly recovered in fragmented or incomplete states (Sharma et al. 2014; Tambawala et al. 2016). However, according to Kiran (2014:77) the skull has been considered the “second best region for sex determination as it is the best-preserved part of the body after death” and Sharma (2014:37) considers the skull to appear to be the “main reliable bone exhibiting sexually dimorphic traits because the skull has high resistance to adverse environmental conditions over time, resulting in the greater stability of dimorphic features as compared to other skeletal bony pieces.” As helpful as the skull may be in the assessment of skeletonized remains for sex identification, when fragmented, it prevents conventional craniofacial markers from being used (Hamed, El-Badrawy, and Fattah 2014).

When other means of identification have failed, and only skull remains have been recovered, the frontal sinus can be used for identification (Kotrashetti et al. 2014). In fragmented remains, the frontal bone may be recovered intact allowing for the frontal
sinuses within to be useful in sex determination (Hamed, El-Badrawy, and Fattah 2014; Tiwari et al. 2016). This is due to the frontal sinus’ ability to be preserved in burned, or dismembered corpses and retrieved after a catastrophe as it is a very sturdy part of the skull (Akhlaghi et al. 2016). Likewise, in cases where the skull and other bones have been badly damaged in casualties where the bone is incinerated, fragmented, or disfigured, the maxillae is preserved enough for the maxillary sinus within to be undamaged (Ahmed et al. 2015; Amin and Hassan 2012; Chandra et al. 2014; Rai et al. 2016; Sharma et al. 2014; Tambawala et al. 2016; Uthman et al. 2011).

Both the maxillary and frontal sinus have distinct characteristics that can contributed to human identification. Maxillary sinuses from various species have exhibited sexual dimorphism, which refers to a systemic difference in the form of shape or size between different sexes within the same species (Kanthem et al. 2015). The frontal sinus morphology is considered to be unique with its peculiar characteristics in regard to its shape, size, and position, allowing for the frontal sinus’ configuration to demonstrate highly individualistic markers that allow for the sinus to assist in personal identification (Goyal et al. 2013; Kiran, Ramaswamy, and Khaitan 2014; Kotrashetti et al. 2014; Mathur et al. 2013; Tiwari et al. 2016). The uniqueness of the frontal sinus has been scientifically demonstrated through several studies in literature, allowing for the sinus’ variations to be used successfully as the bases for forensic identification (Kotrashetti et al. 2014; Michel et al. 2015). The unique quality of the frontal sinus has
even been demonstrated on the level of individuality amongst monozygotic twins, just like fingerprints (Mathur et al. 2013; Tiwari et al. 2016).

The frontal sinus configurations and individualist qualities have been established through two and three-dimensional visualizations on radiographs and computed tomographic scans (Goyal et al. 2013). The frontal sinus has been reliable in forensic identification of human remains when both antemortem and postmortem radiographs have been available for comparison (Kotrashetti et al. 2014). Radiography is used in forensic pathology commonly with decomposed, fragmented, or burned remains because the images can assist in measuring accurate dimension which can then be applied to formulas in order to identify sex, regardless of whether antemortem radiographs are available (Goyal et al. 2013; Hamed, El-Badrawy, and Fattah 2014; Michel et al. 2015; Tiwari et al. 2016). Mathur (2013;37) considered radiographs to be a good method for identification in their research as they believed it was “simple and not time consuming. It could be easily employed by a general dentist, as it did not require expertise.” as compared to what they considered to be the time consuming and expensive nature of using DNA analysis for identification of unknown remains.

Others however have mentioned limitations to using radiographs for assessment of the paranasal sinuses. Radiographic techniques can have variations in distance, angle and orientation of the cranium which could modify a radiographic image of the frontal sinus and lead to distortion of the anatomical characteristics of the sinus (Kiran, Ramaswamy, and Khaitan 2014). Tiwari (2016) also had apprehensions in regard to the
use of radiologic contributions to the assessment of the maxillary sinus. When the maxillary sinus is undergoing visual inspection, for anatomic measurements and precise measurements of bone dimensions, Tiwari (2016;53) and Akhlaghi (2016;37) believe it often exceeds the contribution that radiology can make, “particularly where identification of skeletal remains is required”.

Contrarily, computed tomographic scans are considered an excellent imaging modality for use with the assessment of sino-nasal cavities by most, due to the fact that it provides accurate assessment of not only the paranasal sinuses, but also of craniofacial bones, as well as the extent of pneumatisation of the sinuses (Ahmed et al. 2015; Kanthem et al. 2015; Sharma et al. 2014; Uthman et al. 2011), and have been applied anthropologically in the study of fossilized skulls (Teke et al. 2006). Computed tomographic scans have been more advantageous than conventional radiographs for many reasons. CT scans can avoid the superimposition of structures beyond the plane of interest to allow visualization of density differences at small levels. Computed tomography also allows for easy manipulation of internal points that when evaluated can be show by segmented images. CT scans have the ability to precisely locate and measure craniometric points more accurately than what can be performed on a conventional radiograph. Computed tomography imaging allows for volumes and areas to be calculated, and the film includes a description of the patient’s details which can be helpful in the identification process (Kanthem et al. 2015). The nature of the contiguous cross-sections provides 3D info that is not easily replicated through radiography, and the
accessibility by means of most hospitals also contributes to the advantageous nature of CT scans (Rai et al. 2016; Teke et al. 2006). Previous articles have stated the ability to obtain precise measurements for the frontal sinus through CT scans (Hamed, El-Badrawy, and Fattah 2014) as well as similar measurements for the maxillary sinus when compared to measurements taken of the actual skull (Rai et al. 2016). Several articles have supported CT imaging with the ability to provide adequate measurements for the maxillary sinus that cannot by approached by other means of imaging (Amin and Hassan 2012; Chandra et al. 2014; Sharma et al. 2014; Uthman et al. 2011.) The necessity for complex imaging systems in order to obtain accurate measurements for assessment of the paranasal sinuses may be due to the unique structural nature of the sinuses.

Frontal sinuses are paired irregularly shaped pneumatized cavities that are located in the frontal bone, posterior to the superciliary arch, and superior to each eye, and extends between the anterior and posterior tables of the ascending portion of the frontal bone (Hamed, El-Badrawy, and Fattah 2014; Kiran, Ramaswamy, and Khaitan 2014; Kotrashetti et al. 2014; Michel et al. 2015; Tiwari et al. 2016). The uniqueness of the frontal sinus continues with the absence, or presence of a septum which typically deviates from the midline of the left and right frontal sinus (Kotrashetti et al. 2014). Each frontal sinus communicates with the nasal fossa, specifically the middle meatus, via the infundibulum, and are triangular, or pyramidal shaped, with the apex superior to its base (Hamed, El-Badrawy, and Fattah 2014; Kotrashetti et al. 2014; Tiwari et al. 2016). The frontal sinus also makes a valid contribution to glabellar contours and the forehead
(Tiwari et al. 2016). The individuality of each frontal sinus is shown through considerable asymmetrical variations in the shape, and capacity of the sinus (Hamed, El-Badrawy, and Fattah 2014; Kotrashetti et al. 2014; Tiwari et al. 2016). Structure and size of the sinus can be influenced by genetic and environmental factors, including but not limited to, pathology, craniofacial configuration, thickness of the frontal bone, and hormonal levels (Soman, Sujatha, and Lingappa 2016). Individuals with high sports activity levels may also experience structural and developmental changes such as hyperpneumatisation (Kiran, Ramaswamy, and Khaitan 2014).

The frontal sinus develops from an ethmoidal cell as diverticula that originates from the lateral aspect of the nasal wall approximately during the fourth intrauterine month, following the development of a recess (Akhatghi et al. 2016; Mathur et al. 2013; Michel et al. 2015). The asymmetrical configuration of the frontal sinuses can be contributed to unequal reabsorption of the diploe during the development of the sinuses (Soman, Sujatha, and Lingappa 2016). Although the frontal sinus begins to develop during utero, it is not actually visible at birth, but appears at the second year of life, and is well developed by the seventh, or eighth year (Kotrashetti et al. 2014; Mathur et al. 2013; Tiwari et al. 2016). The frontal sinus completes its development by age 20, and does not typically change during adulthood due to the sinus’ strong walls (Goyal et al. 2013; Hamed, El-Badrawy, and Fattah 2014; Kotrashetti et al. 2014; Mathur et al. 2013; Michel et al. 2015). The frontal sinus can experience changes in old age due to several reasons. The sinus may become larger due to bone reabsorption causing the walls to thin as the
individual ages (Kotrashetti et al. 2014; Michel et al. 2015). Contrarily, the frontal sinus may also appear atrophic, or become smaller, due to pathological events such as fractures, tumors, or severe infections, as well as gradual pneumatisation (Goyal et al. 2013, Hamed, El-Badrawy, and Fattah 2014; Michel et al. 2015). The absence of a paranasal sinus is uncommon, and typically only occurs in the frontal sinus (Akhlagh et al. 2016). Absence of the frontal sinus occurs in only 2.00-4.00% of the sample with bilateral absence occurring in only 5.00%, and unilateral 4.00% (Akhlagh et al. 2016; Mathur et al. 2013). These percentages are known to differ to an extent, dependent on ethnic sample, of which the Eskimo sample has the highest occurrence, which is believed to have developed as an adaption to their climate conditions (Soman, Sujatha, and Lingappa 2016).

Maxillary sinuses are found centrally located in the maxillary bone and develop to different sizes and shapes unique to each individual (Ahmed et al. 2015; Amin and Hassan 2012; Chandra et al. 2014; Daraze, Hoteit, and Youness 2016; Kanthem et al. 2015; Tambawala et al. 2016; Teke et al. 2006). Thin walls encase the maxillary sinus which superior tip can extend into the zygomatic process and occupy portions of the zygomatic bone (Ahmed et al. 2015; Amin and Hassan 2012; Chandra et al. 2014; Kanthem et al. 2015; Teke et al. 2006). The base of the maxillary sinus is formed by the alveolar process of the maxilla that holds the superior posterior teeth (Ahmed et al. 2015; Amin and Hassan 2012; Kanthem et al. 2015; Teke et al. 2006). The maxillary sinuses extension into the roof of permanent teeth upon the release of deciduous teeth plays a role
in teeth movement within proximity of the sinus (Ahmed et al. 2015; Chandra et al. 2014; Daraze, Hoteit, and Youness 2016; Teke et al. 2006). The roots of canine teeth, as well as the molars have the potential to elevate the maxillary sinuses, or even perforate the floor (Kanthem et al. 2015; Teke et al. 2006).

The maxillary sinus begins to develop at the end of the second embryonic month (Ahmed et al. 2015; Amin and Hassan 2012; Tambawala et al. 2016; Teke et al. 2006). Their unique development as invaginations of nasal mucosa within the maxillary bone, helps explain the vast anatomical variations between maxillary sinuses (Ahmed et al. 2015; Chandra et al. 2014). The maxillary sinus is the largest paranasal sinus, and appears in most individuals by the age of five, and begins to undergo shape and volume changes, which leads to the sinus floor becoming level with the nasal floor by the age of 12-13 years old, and continues to develop along with the permanent dentition until the age of 20, when the sinuses should have reached 5mm inferior to the nasal floor (Ahmed et al. 2015; Amin and Hassan 2012; Chandra et al. 2014; Sharma et al. 2014; Tambawala et al. 2016; Teke et al. 2006; Uthman et al. 2011). The stabilized status of the maxillary sinus can change in adulthood in reference to size and shape due to the loss of teeth, as well as environmental factors such as genetic diseases, and post infections that may contribute (Chandra et al. 2014; Rai et al. 2016; Teke et al. 2006).

Aim of Study:

The individualistic qualities of the frontal and maxillary sinuses make for valid areas of scientific research aimed at sex identification. There has been minimal published
research in the area of sex identification within the regions of the paranasal sinuses, despite knowledge of sexual dimorphism. Equally so, there has not been an article published on the attempt of identifying sexual dimorphism on the same sample, comparing results of the maxillary, and frontal sinuses individually, to identify which paranasal sinus would obtain higher accuracy results in sex identification. Thus, the aim of this study was to perform a retrospective study on archived CT scans measuring their parameters in an attempt to identify the assumed sexual dimorphism and determine the accuracy of previous established methods of sex identification. Specific research questions include:

- Is there intra-observer error between measurements of frontal sinus volume?
- Is there a difference between male and female frontal sinus total volumes?
- What are the accuracy rates of the frontal sinus formula established by Michel et al. (2015)?
- Is there a difference between right and left parameters of the maxillary sinus?
- Is there a difference between male and female maxillary sinus for various parameters?
- What are the accuracy rates of the maxillary sinus formulas established by Rai et al. (2016)?
Chapter 2: Materials and Methods

This study was performed retrospectively on computed tomography (CT) scans in the previously established database of the Injury Biomechanics Research Center (IBRC) at The Ohio State University. Images of 57 subjects (30 male, 27 female) aged between 36 and 87 who had been scanned by the IBRC were used for collecting measurements. Mean age of the female sample was 62.26 years old (range of 36-87 years), with the mean age of males being 66.82 years old (range of 40 to 88 years). Refer to Figure 1 for a representation of the sample ages by decade.

Figure 1: Histogram of sample divided by sex and organized by age decades (years)
The IBRC’s post-mortem human surrogate (PMHS) log was utilized to identify subject identification numbers that would include CT scans of the cranium. The sex of this sample was known; however, the observer was blinded to known sexes, during the retrieval of the measurements, and the application of previously established formulas during the attempt to determine sex. Osirix software (Pixmeo, Geneva Switzerland) was used to obtain all linear and volume measurements collected for this study by a single operator.

CT image files, with a slice thickness of 0.625, were then uploaded to the Osirix software database for examination. The CT slice thickness was 0.625The study was designed to measure volume of the frontal and maxillary sinus, as well as the medial-lateral, superior-inferior, and anterior-posterior dimensions of the maxillary sinus, in an attempt to replicate a previously established frontal sinus formula by Michel et al. (2015), and three maxillary sinus formulas established by Rai et al. (2016), used for sex identification. This was done in an effort to identify a preferential sinus for sex identification.

Frontal Sinus Methods

The following portion of the study was an attempt to replicate and verify findings of Michel et al. (2015). The formula being used for the frontal sinus application of sex identification only required the volumes of each sinus to be obtained, albeit twice. Volume measurements of the right and left frontal sinus were obtained separately from
each subject, and then combined for a total frontal sinus volume. The frontal sinus was outlined using the pencil tool in Osirix to trace the sinus cavity by slice (Figure 2). The operator then manually adjusted the points until the ROI outline matched the sinus outline to the best of their ability (Figure 3).

Figure 2: Original frontal slice ROI outline before correction
Upon completion of an outline on every CT slice that the sinus was visible, the operator utilized the “ROI volume rendering” tool to obtain the total sinus volume and results were reported in cubic centimeters (Figure 4).
This process was then replicated a second time for each individual sinus, with the first and second set of measurements taken a week apart. Only one subject was found to have a unilateral frontal sinus absence on the right side in the male sample, with no absence either unilateral, or bilateral present in the female sample. When a complete septum between the right and left sinus was not found, a continuation of the most medial septal point was used as a separation point between right and left sinuses (Figure 5).
Maxillary Sinus Methods

The maxillary portion of the study was designed to replicate and attempt to verify findings of Rai et al. (2016). The formula being used for the maxillary sinus application of sex identification required several measurements other than volume, and each sinus was considered individually (left or right). All linear measurements were taken utilizing
the 3D MPR option in Osirix. All axes were then adjusted within the plane to allow for a completely unturned coronal, or transverse view before proceeding with measurements (Figure 6).

For the anterior-posterior measurement, the Michel et al. (2015) noted the CT scan slice number of the most anterior aspect of the sinus, as well as the most posterior. The number of total slices was then obtained, and subsequently multiplied by the thickness of the CT slices. In the current study, the operator obtained the anterior-
posterior dimension by utilizing the length tool in Osirix after previously adjusting the view for a transverse section in 3D MPR, and took measurements on every CT slice stretching from the most anterior point, to the most posterior point (Figure 7). Upon completion, the maximum distance was then recorded as the anterior-posterior dimension for that sinus. This was repeated for each individual sinus among all 57 subjects within the study.
For the superior-inferior measurements, the length tool in Osirix was utilized again in each slice in an adjusted 3D MPR coronal view of the maxillary sinus. Each CT

Figure 7: Representation of an anterior-posterior measurement in the maxillary sinus

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scan slice was measured from the most superior point, to the most inferior point, before the maximum dimension was recorded as the superior-inferior dimension (Figure 8).

Figure 8: Representation of a superior-inferior measurement in the maxillary sinus
Similarly, each sinus was measured by the length tool, from its most medial point, to the most lateral point, and the maximum measurement was obtained for the medial-lateral dimension (Figure 9). These methods were once again applied to each individual sinus among all 57 subjects within the study.

Figure 9: Representation of a medial-lateral measurement in the maxillary sinus
For the maxillary sinus volume measurement, the same methods were applied as the frontal sinus. Volume measurements of the right and left maxillary sinus were obtained separately from each subject. The maxillary sinus was outlined using the pencil tool in Osirix to trace the sinus cavity by slice (Figure 10).

Figure 10: Original maxillary sinus tracing before correcting ROI points
The operator then manually adjusted the points until the ROI outline matched the sinus outline to the best of their ability (Figure 11).

Figure 11: Manually adjusted ROI points for volume tracing
Upon completion of an outline on every CT slice that the sinus was visible, the operator utilized the “ROI volume rendering” tool to obtain the total sinus volume and results were reported in cubic centimeters (Figure 12).

![ROI Volume Example](image)

Figure 12: ROI rendered volume example of the maxillary sinus

Neither the maxillary sinus, nor the frontal sinus required adjusting the CT image under 3D MPR for an unturned view, as it would not affect the results of the volume measurements. All linear measurements were reported in centimeters, and converted into
millimeters before application in the maxillary sinus formula. Volume values for the frontal sinus required being converted from cm$^3$ to mm$^3$ for application in the frontal formula. Both linear, and volumetric measurements taken were manually recorded in an excel datasheet.

Frontal Sinus Formula Application

In an attempt to replicate and test their validity, measurements of total sinus volume obtained during this study were applied to formulas previously established by Michel et al. (2015):

\[
F_0 \text{ (Males)} = 4.359 \times 10^{-4} \times \text{total frontal sinus volume} - 2.763 \quad (1)
\]

\[
F_1 \text{ (Females)} = 2.368 \times 10^{-4} \times \text{total frontal sinus volume} - 1.283 \quad (2)
\]

The probability of a subject belonging to the male or female sample was then determined by the following formulas established by Michel et al. (2015):

\[
P_0 \text{ (Male)} = \frac{\exp(F_0)}{\exp(F_0) + \exp(F_1)} \quad (3)
\]

\[
P_1 \text{ (Female)} = \frac{\exp(F_1)}{\exp(F_0) + \exp(F_1)} \quad (4)
\]
The total frontal sinus volume was applied to formulas 1, and 2, to obtain variables for F0, and F1. These values were then applied to the probability formulas (3 and 4) to obtain a percent value. The obtained percent value of P0 provided the probability that the subject belonged in the male classification, and the P1 provided probability of the subject belonging in the female classification. If the probability was found to be over 50.00%, the subject was predicted as that sex.

Application of Maxillary Sinus Formulas

When attempting to replicate findings of Rai et al. (2016), the following formulas were used to identify the sex of each individual within the total sample (57 subjects, 30 males, 27 female):

The right maxillary sinus formula is:

\[
\text{Sex} = -5.116 - 0.159 \times \text{MLR} - 0.014 \times \text{SIR} + 0.171 \times \text{APR} + 0.218 \times \text{VR}
\]  

(5)

The left maxillary sinus formula is:

\[
\text{Sex} = -0.720 - 0.258 \times \text{MLL} - 0.146 \times \text{SIL} + 0.120 \times \text{APL} + 0.586 \times \text{VL}
\]  

(6)
The right and left maxillary sinus formula is:

\[
\text{Sex} = 4.033 - 0.101 \times \text{MLR} - 0.21 \times \text{SIR} + 0.397 \times \text{APR} + 0.118 \times \text{VR} - 0.23 \times \text{MLL} - 0.014 \times \text{SIL} - 0.417 \times \text{APL} + 0.358 \times \text{VL} \tag{7}
\]

Where MLR referred to the medial-lateral dimension of the right sinus, SIR the superior-inferior dimension of the right sinus, APR the anterior-posterior dimension of the right sinus, and VR the volume of the right maxillary sinus. Likewise, the MLL referred to the medial-lateral dimension of the left sinus, SIL the superior-inferior dimension of the left sinus, the APL anterior-posterior dimension of the left sinus, and VL the volume of the left maxillary sinus. When the sum of a formula derived above substituted with the appropriate values, a numeric value is obtained for “Sex”. When this value is positive, the sex is predicted to be within the male sample, when it is found to be negative, the sex is predicted to be within the female sample (Rai et al. 2016).

Statistical Analysis

Statistical analysis was completed using SPSS software version 24 (IBM, New York United States). Normality tests were first performed on all data sets. Subsequently, either parametric or non-parametric statistical tests as appropriate were employed to test for differences between sample distributions, sexes and sides.
Chapter 3: Results

Age Data

Normality tests were performed on both the female and male age data distributions (Table 1). The female normality test had a P value of 0.280, and the male normality test resulted in a P value of 0.348, indicating that both were normally distributed.

Table 1: Normality test on age results for female and male samples

<table>
<thead>
<tr>
<th>Sex</th>
<th>Statistic</th>
<th>df</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>0.962</td>
<td>30</td>
<td>0.348</td>
</tr>
<tr>
<td>Female</td>
<td>0.955</td>
<td>27</td>
<td>0.280</td>
</tr>
</tbody>
</table>

In order to determine if the samples for each sex were comparable and had equal age distributions, an independent sample t-test between the females and males was run, which yielded a nonsignificant statistical difference between their ages (Table 2). This finding supports the use of the male and female samples that spanned a wide age range.
Table 2: Independent Sample T-Test on Age Data Between Males and Females

<table>
<thead>
<tr>
<th></th>
<th>t</th>
<th>df</th>
<th>P-value (2-tailed)</th>
<th>Mean Difference</th>
<th>Std. Error Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male vs female</td>
<td>-1.22</td>
<td>55</td>
<td>0.23</td>
<td>-4.56</td>
<td>3.73</td>
</tr>
</tbody>
</table>

Frontal Sinus Results

*Intraobserver Error*

The total volume of the frontal sinus on the entire sample (n = 57) was measured twice by the same observer to assess the variance in measurements of the same feature. The frontal sinus statistical analysis began with a normality test performed on the frontal sinus volume samples of data set 1, and data set 2 separately to determine the normality of distribution (Table 3).

Table 3: Normality Test Results for Data Set One and Two

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Statistic</th>
<th>df</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.89</td>
<td>57</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>2</td>
<td>0.89</td>
<td>57</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>
Non-normal distributions (p<0.0001), led to a Wilcoxon signed rank test being performed between the two sets of observations to determine if there was a significant difference. Since a significant difference was found between the observations (p<0.0001) (Table 4), all further analysis utilized only dataset 2, and extreme caution should be used when interpreting results.

Table 4: Wilcoxon Sign Rank Test Comparing Data Set One to Data Set Two

<table>
<thead>
<tr>
<th></th>
<th>Z</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data set 1 and 2</td>
<td>-3.66</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

_Difference Between Sexes in the Frontal Sinus_

Descriptive statistics for the total frontal sinus volume by sex are provided in Table 5 Shapiro-Wilk normality tests were performed on data set two, of the males, and females separately (Table 5). The male sample was normality distributed (p=0.075) but the female sample was not (p<0.0001; Table 6), so a non-parametric Mann Whitney test was performed to compare sexes. Results indicate no significant difference between male and female values for the total frontal sinus volumes (p = 0.195, Table 7). A box plot illustrating the lack of sexual dimorphism in frontal sinus volume can be found in Figure 13.
Table 5: Descriptive Statistics for the Frontal Sinus Volume in the Male and Female Samples

<table>
<thead>
<tr>
<th>Sex</th>
<th>Minimum (mm$^3$)</th>
<th>Maximum (mm$^3$)</th>
<th>Mean (mm$^3$)</th>
<th>SD (mm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>210.20</td>
<td>24544.00</td>
<td>10946.78</td>
<td>6985.92</td>
</tr>
<tr>
<td>Female</td>
<td>2063.50</td>
<td>36465.80</td>
<td>7503.012</td>
<td>9670.37</td>
</tr>
</tbody>
</table>

Table 6: Normality Test Results for Male and Females

<table>
<thead>
<tr>
<th>Sex</th>
<th>Statistic</th>
<th>df</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>0.94</td>
<td>30</td>
<td>0.075</td>
</tr>
<tr>
<td>Female</td>
<td>0.78</td>
<td>27</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Figure 13: Box plot of frontal sinus total volumes in the female and male samples

Table 7: Mann Whitney Test Results Comparing Male and Female Frontal Sinus Total Volume

<table>
<thead>
<tr>
<th>Z</th>
<th>P-value</th>
<th>df</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1.297</td>
<td>0.195</td>
<td>56</td>
</tr>
</tbody>
</table>

Sex identification accuracy with the method previously established by Michel et al. (2015) was variable between sexes. The overall accuracy rate of the frontal sinus
application in the current study, is 59.60%. Utilizing the formula provided, sex was accurately predicted in 66.67% percent of males and only 51.85% of females (Table 8).

Table 8: Frontal Sinus Formula Accuracy Results

<table>
<thead>
<tr>
<th>Accuracy Rate</th>
<th>Male</th>
<th>Female</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>66.67%</td>
<td>51.58%</td>
<td>59.60%</td>
</tr>
</tbody>
</table>

Maxillary Sinus Results

_Difference Between Right and Left Maxillary Sinus_

A normality test on each maxillary sinus parameter within each sinus, in the male, and female samples separately indicates that most variables are normally distributed (Table 9). Subsequently, paired sample t-tests between the left and right show no difference for any maxillary sinus variable in males or females (p = 0.156 – 0.676; Table 10).
Table 9: Normality Test Results for Maxillary Sinus Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Side</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Male</td>
<td>Female</td>
<td></td>
<td>Male</td>
<td>Female</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Statistic</td>
<td>df</td>
<td>P-value</td>
<td>Statistic</td>
<td>df</td>
<td>P-value</td>
<td></td>
</tr>
<tr>
<td>Superior-Inferior</td>
<td>Left</td>
<td>0.98</td>
<td>30</td>
<td>0.720</td>
<td>0.98</td>
<td>27</td>
<td>0.799</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>0.97</td>
<td>30</td>
<td>0.480</td>
<td>0.95</td>
<td>27</td>
<td>0.241</td>
<td></td>
</tr>
<tr>
<td>Medial-Lateral</td>
<td>Left</td>
<td>0.97</td>
<td>30</td>
<td>0.418</td>
<td>0.96</td>
<td>27</td>
<td>0.395</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>0.98</td>
<td>30</td>
<td>0.866</td>
<td>0.91</td>
<td>27</td>
<td>0.018</td>
<td></td>
</tr>
<tr>
<td>Anterior-posterior</td>
<td>Left</td>
<td>0.97</td>
<td>30</td>
<td>0.414</td>
<td>0.98</td>
<td>27</td>
<td>0.727</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>0.96</td>
<td>30</td>
<td>0.362</td>
<td>0.94</td>
<td>27</td>
<td>0.155</td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>Left</td>
<td>0.97</td>
<td>30</td>
<td>0.866</td>
<td>0.96</td>
<td>27</td>
<td>0.454</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>0.96</td>
<td>30</td>
<td>0.248</td>
<td>0.95</td>
<td>27</td>
<td>0.262</td>
<td></td>
</tr>
</tbody>
</table>

Table 10: Paired Sample Test Results Comparing Right to Left Maxillary Sinus for all Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td></td>
<td>Female</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>t</td>
<td>df</td>
<td>P-value</td>
<td>t</td>
<td>df</td>
<td>P-value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superior-Inferior</td>
<td>-0.51</td>
<td>29</td>
<td>0.720</td>
<td>-1.22</td>
<td>26</td>
<td>0.235</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medial-Lateral</td>
<td>1.22</td>
<td>29</td>
<td>0.231</td>
<td>0.55</td>
<td>26</td>
<td>0.588</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior-posterior</td>
<td>0.42</td>
<td>29</td>
<td>0.676</td>
<td>-0.92</td>
<td>26</td>
<td>0.356</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>-1.46</td>
<td>29</td>
<td>0.156</td>
<td>0.82</td>
<td>26</td>
<td>0.418</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Difference Between Males and Females in the Maxillary Sinus

Since no side differences were found between maxillary sinus measures, only the left side was used for further comparison between the sexes. Descriptive statistics for the various maxillary sinus parameters can be found in Table 11, followed by a visual depiction in Figure 14. All male and female maxillary sinus variables were normally distributed (p = 0.395 – 0.799; Table 12), and most parameters did not vary significantly between the sexes, with the exception of the superior-inferior linear measurement (Table 13) which was determined from the results of an independent sample test. Medial-lateral linear length was found to have a statistically significant value (p=0.048), similarly to the anterior-posterior length of the maxillary sinus (p=0.047), however neither of these reached the statistical significance of the superior-inferior linear length (p=0.003). Although both the medial-lateral, and anterior-posterior linear lengths were found to be statistically significant, the strength of this significance was weak, and should not be valued highly in sexual dimorphism, similar to the volume, which was found to have a nonsignificant statistical value (p=0.069; Table 12).
Table 11: Descriptive Statistics for the Left Maxillary Sinus Parameters in Males and Females

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sex</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superior-Inferior (mm)</td>
<td>Male</td>
<td>31.30</td>
<td>50.40</td>
<td>42.22</td>
<td>4.46</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>32.00</td>
<td>45.50</td>
<td>38.78</td>
<td>3.54</td>
</tr>
<tr>
<td>Medial-Lateral (mm)</td>
<td>Male</td>
<td>26.80</td>
<td>45.60</td>
<td>35.11</td>
<td>4.73</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>24.10</td>
<td>38.40</td>
<td>32.87</td>
<td>3.25</td>
</tr>
<tr>
<td>Anterior-posterior (mm)</td>
<td>Male</td>
<td>36.20</td>
<td>48.70</td>
<td>41.35</td>
<td>3.28</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>33.00</td>
<td>46.20</td>
<td>39.54</td>
<td>3.31</td>
</tr>
<tr>
<td>Volume (cm$^3$)</td>
<td>Male</td>
<td>7.268</td>
<td>38.24</td>
<td>21.13</td>
<td>6.85</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>10.12</td>
<td>24.06</td>
<td>18.37</td>
<td>3.45</td>
</tr>
</tbody>
</table>

Figure 14: Box plot of left maxillary sinus linear measurements between the male and female samples
Figure 15: Box plot of left maxillary sinus volumes of the male and female sample
Table 12: Left Male and Female Maxillary Sinus Normality Test

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sex</th>
<th>Statistics</th>
<th>df</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superior-Inferior</td>
<td>Male</td>
<td>0.98</td>
<td>30</td>
<td>0.720</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>0.98</td>
<td>27</td>
<td>0.799</td>
</tr>
<tr>
<td>Medial-Lateral</td>
<td>Male</td>
<td>0.97</td>
<td>30</td>
<td>0.418</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>0.96</td>
<td>27</td>
<td>0.395</td>
</tr>
<tr>
<td>Anterior-posterior</td>
<td>Male</td>
<td>0.97</td>
<td>30</td>
<td>0.414</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>0.98</td>
<td>27</td>
<td>0.727</td>
</tr>
<tr>
<td>Volume</td>
<td>Male</td>
<td>0.97</td>
<td>30</td>
<td>0.585</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>0.96</td>
<td>27</td>
<td>0.454</td>
</tr>
</tbody>
</table>

Table 13: Independent Sample T-Test Results Between Male and Female Left Maxillary Sinus

<table>
<thead>
<tr>
<th>Parameter</th>
<th>t</th>
<th>df</th>
<th>P-value</th>
<th>Mean Difference</th>
<th>Std. Error Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superior-Inferior</td>
<td>3.14</td>
<td>55</td>
<td>.003</td>
<td>3.44</td>
<td>1.10</td>
</tr>
<tr>
<td>Medial-Lateral</td>
<td>2.02</td>
<td>55</td>
<td>0.048</td>
<td>2.24</td>
<td>1.11</td>
</tr>
<tr>
<td>Anterior-posterior</td>
<td>2.04</td>
<td>55</td>
<td>0.047</td>
<td>1.81</td>
<td>0.89</td>
</tr>
<tr>
<td>Volume</td>
<td>1.86</td>
<td>55</td>
<td>0.069</td>
<td>2.76</td>
<td>1.49</td>
</tr>
</tbody>
</table>
Utilizing the previously established methods of sex prediction, the accuracy was calculated by dividing the total amount of correctly identified individuals, by the total amount of the sample, and was found to be variable. An observation of accuracy rates of sex prediction from the dimensions of the right and left maxillary can be seen in Table 14.

Table 14: Maxillary Sinus Formula Accuracy Rates

<table>
<thead>
<tr>
<th>Formula</th>
<th>Sex</th>
<th>Accuracy Rates</th>
<th>Overall Accuracy Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>Male</td>
<td>60.00%</td>
<td>61.40%</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>62.96%</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>Male</td>
<td>70.00%</td>
<td>52.60%</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>33.33%</td>
<td></td>
</tr>
<tr>
<td>Right &amp; Left Maxillary</td>
<td>Male</td>
<td>0.00%</td>
<td>47.38%</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>100.00%</td>
<td></td>
</tr>
</tbody>
</table>
Chapter 4: Discussion

Frontal Sinus Results

Tests for intra-observer error between observation one and two for the frontal sinus volume measurements proved to have a statistically significant difference \((p < 0.0001)\). This strongly suggests there is an inherent error in measurement, due to the significant difference found between the first, and second set of measurements, which could affect the outcome of the current study. However, it was assumed this error was CT scan and observer related, and since the exact same methods were utilized and all CT scans were acquired the same, it is possible that the error is at least applied consistently throughout the study. Readers are urged to take this into consideration when reviewing the results of this study, and future work should include a comprehensive evaluation of intra- and inter-observer error.

No significant difference was found between the sexes’ frontal sinus volumes \((p=0.195)\). The lack of a significant difference between males and females renders the frontal sinus incapable of determining sex based on volume measurements alone, which led to the relatively low overall accuracy rates \((59.60\%)\) utilizing the frontal volume formula established by Michel et al. (2015).

The reasoning behind the lack of sexual dimorphism between the male and female samples of this study could be attributed to various aspects of the current study, and
differences between the replication. Michel et al. (2015) utilized CT scans from live subjects that were referred to a specified clinic, and thus had more control over selection of their sample size and ability to exclude subjects based on known medical history, which was not an option for the current study. Thus exclusions of subjects with a history of sinus pathology issues could be excluded as possible outliers before measurements were obtained by Michel et al. (2015). Meanwhile, no medical history of the selected sample of the current study made the exclusion of subjects with a history of sinus health issues, which could potentially change the structure of an impacted sinus, impossible.

The proven statistical difference between data set one, and data set two of the frontal sinus volumes also urges questions of a possibility in measurement error that could have potentially led to misinterpreted statistical results within the current study. Likewise, a potential difference in CT image resolution could have contributed to the varying results of Michel et al. (2015) and the current study, as various image resolutions could depict seemingly different frontal sinus borders which would result in a difference in ROI tracing and eventually, the rendered ROI volume of the frontal sinus.

Maxillary Sinus Results

No differences were found between left and right maxillary sinus linear or volume measurements. The lack of statistically significant difference between the right and left measurements allowed the observer to perform the comparison between sexes utilizing just one sinus’ parameters. This implies that future work may not need to measure both
sinuses for sex determination. When comparing the maxillary sinus parameters between the sexes, statistically significant differences were found in every parameter except the maxillary sinus volume. This suggests that using linear dimensions of the maxillary sinus would be more appropriate in the process of sex determination that volumetric parameters. However, the statistically significant differences were weak in both the medial-lateral linear measurements as well as the anterior posterior measurement.

Future research should consider focusing on the maxillary sinus superior-inferior linear measurements when developing sex determination formulas due to this parameter having the highest statistically significant difference (P=0.003) amongst the parameters used in the current study.

Other Method’s Accuracy Rates

In comparison to other studies performed on the maxillary and frontal sinus in an attempt at sexual identification, the present study still yielded lower accuracy rates. Methods of sex identification using just the frontal sinus resulted in similarly higher accuracy rates than the current study. Akhlaghi et al. (2016), identified 7 parameters in an attempt to accurately identify the sex of an unknown individual. These parameters included maximum distance between the anterior and posterior sinus walls, maximum distance between the outermost borders of the right and left sinus walls, maximum distance between the innermost and the outermost borders of the sinus walls, maximum distance between the upper and lower sinus wall borders, parts of the sinus wall lying
between septa, septa incompletely extending from one sinus wall to the other wall and dividing the sinus into several compartments, and septa running from one sinus wall to the other wall and completely dividing the sinus into several compartments. This method resulted in an overall accuracy rate of 61.09%. Kotrashetti et al. (2014) attempted to identifying sex with the frontal sinus using the right height, left height, right width, left width, left area, and right area with predetermined baselines, and observed an overall accuracy rate of 64.6%. Hamed, El-Badrawy, and Fattah (2014) attempted sex identification of the frontal sinus using measurements for the height, transverse, and anteroposterior lengths, and resulted in an overall accuracy rate of 67.0%. Kiran, Ramaswamy, and Khaitan (2014) resulted in an overall accuracy rate of 67.59% of sex identification using measurements for the length, width, and sinus index of the frontal sinus. Mathur et al. (2013) attempted sex identification using the maximum height and width of frontal sinuses with a previously standardized baseline and yielded an overall accuracy rate of 88.00%. Once again, all of the beforementioned methods resulted in higher overall accuracy rates than the present study at 59.60% using the frontal sinus. The discrepancy of sexual dimorphism between the current study, and the beforementioned methods could be attributed to the vast difference in parameters used for sex determination. No linear measurements were utilized in the current study, whereas linear measurements were the focus in every other frontal sinus method previously mentioned. The current study overlooked this inconsistency in favor of the higher accuracy rates claimed by Michel et al. (2015) in hopes that the difference in linear versus volumetric
parameters was the reason behind the higher accuracy rate of 72.50%. This suggests the possibility of sexual dimorphism in the frontal sinus amongst linear parameters despite the current study having determined no sexual dimorphism in the frontal sinus volume. Higher accuracy rates of other frontal sinus methods could also be attributed to formulae being developed based on parameters from a single sample, and then being applied to the same sample used to determine the formulae. Without applying an established method of sex determination formula to a new sample population, the formula’s accuracy rate should be considered with caution.

Ahmed et al. (2015) attempted to use maximum measurements of width, length, and height of the maxillary sinus in an attempt to identify sex of unknown individuals, and yielded an overall accuracy rate of 63.90%. Amin and Hassan (2012) attempted to identify sex of an unknown individual using the maxillary sinus and taking eight measurements (right antero-posterior, left antero-posterior, right transverse, left transverse, right cephalon-caudal, left cephalon-caudal, right size, and left size) and resulted in an overall accuracy rate of 66.70%. In Sharma et al. (2014) measurements of antero-posterior, height, transverse/width, and volume were obtained from the maxillary sinus, and resulted in an overall accuracy rate of sex identification of 67.03%. Teke et al. (2006) considered measurements for the width, length, and height of the maxillary sinus and resulted in 69.30% accuracy rate of sex identification. Uthman et al. (2011) considered width, length, height, and the total distance across both sinuses in an attempt at sex identification, and resulted in an overall accuracy rate of 73.90%. All of which,
exceeded the overall accuracy rate of the present study with the maxillary sinus of 61.40%.

Mean values for most parameters of the maxillary sinus were found to be generally smaller in similar maxillary sinus methodology articles, than in the current study (Table 15), except for male values in Uthman et al. (2011). Sample populations between similar articles varied greatly, and Teke et al. (2006) was the only study compared to that had a sample originating from the United States of America. All of the articles compared to had the ability to use larger samples of live subjects allowing for the exclusions of subjects with a history of sinus health issues, which could contribute to the difference in means of the linear and volumetric measurements between these studies and the current.

There were also several differences in methods of measurements between the current study, and the comparative studies. The only other study that obtained volumes for the maxillary sinus did so by applying a formula to previously taken linear measurements, which could potentially have contributed to the smaller volume values found by Sharma et al. (2014). Sharma et al. (2014) also took transverse (medial-lateral) measurements perpendicular to the sides of the maxillary sinus compared to the angled measurements from the most lateral point, to the most medial point of the maxillary sinus in the current study. A perpendicular method of measurement was also found in the collection of height (superior-inferior) measurements in the study by Ahmed et al. (2015). Similarly, Uthman et al. (2011) took width (medial-lateral) measurements at a parallel
level to the hard palate. These all differ from the angled method of measurement for linear dimensions in the current study. Lastly, Teke et al. (2007) obtained height (superior-inferior) measurements by noting the slice number of the most superior presence of the sinus, and the most inferior presence of the sinus, then determined how many slices the sinus was visible on total, and multiplied by the slice thickness rather than obtaining an actual linear measurement of the height. All of these differences in measurement methods could contribute to the reasoning behind mostly smaller mean values in the comparative studies.

Higher accuracy rates of other maxillary sinus methods was also believed to be credited to the various formulae being developed based on parameters from a single sample, and then being applied to the same sample used to determine the formulae. Similarly, to issues with frontal sinus methods, without applying an established method of sex determination formula to a new sample population, the formula’s accuracy rate should be considered with caution.
<table>
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<tr>
<th>Article</th>
<th>Sex</th>
<th>Superior-Inferior (mm)</th>
<th>Medial-Lateral (mm)</th>
<th>Anterior-Posterior (mm)</th>
<th>Volume (cm³)</th>
</tr>
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<td>Mean</td>
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<td>Teke et al.</td>
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</table>
Replicated Study’s Accuracy Rates

The current study resulted in overall accuracy rates that were much lower than their replicated counterpart. With comparison to Michel et al. (2015), this study resulted in a lower accuracy rate of 59.60% overall, comparative to their results of 72.50% accuracy of sex identification utilizing the frontal sinus. Rai et al. (2016) resulted in an overall accuracy rate of 80.00% when utilizing just the right maxillary sinus parameters, comparative to the present study’s results of 61.40%. Rai et al. (2016) also saw high accuracy rates utilizing just the left maxillary sinus parameters at an overall accuracy of 73.30% comparative to the present study’s results of 52.60%. Lastly, Rai et al. (2016) combined maxillary sinus parameter formula resulted in an accuracy rate of 83.30% comparative to the present study’s results of 47.38%.

There were only two areas where individual sex identification accuracy rates of the present study surpassed the accuracy rates of Rai et al. (2016). These areas included the accuracy rates of the male sample utilizing only the left maxillary sinus formula, as well as the accuracy rates for the female sample utilizing only the combined formula. In the case of the male sample, the present study yielded an accuracy rate of 70.00% compared to Rai et al. (2016) results of 66.70% in the case of the left maxillary sinus formula. In the present study, using the combined maxillary sinus formula yielded a 100.00% sex identification accuracy rate in the female sample compared to the 86.70% in the results of Rai et al. (2016). However, in the present study, all 57 subjects identified as
female when using the combined sinus formula (0% accuracy), and thus the results should not lead to this method being considered a valid method of sex identification.

Differences Between Current and Replicated Studies

Several areas of the current study varied from the replicated study in aspects of sample populations, methods of data collection, the application of the frontal sinus formula, and potentially methods of data analysis. The present study’s sample size, and sample ethnicity differed from both study replications. The current study originated from the United States, and contained a total of 57 subjects, comparatively to the frontal sinus study (Michel et al. 2015), which had a sample population with French ancestry, and contained a total of 69 patients, compared to the maxillary sinus study (Rai et al. 2016), with a sample ancestry was from India, and a total of 30 patients. It is not believed that the difference in sample sizes could have contributed to the difference in accuracy rates, however, a difference in ancestry, as well as the CT scans being obtained on living individuals in the replicated study, comparatively to deceased individuals in the current study, could contribute to varying results, specifically that no sex differences were identified at all in our study. Further studies should be done on the sample of the United States where there is a greater variance in ancestry, and may result in a necessity for new formulas to be developed for population-specific sex identification methods.

The current study also differed from the data collection methods performed by Rai et al. (2016). The maxillary sinus anterior-posterior linear measurements were taken
using the length tool in Osirix in an axial plane to find the maximum linear measurement for each sinus. This compares to the methods of noting the first and last slide the maxillary sinus was present on, and then multiplying by the slice thickness to obtain a measurement which was performed in Rai et al. (2016). A second aspect of data collection difference may be in the orientation of CT slice sections measured. Rai et al. (2016) did not discuss reorienting the CT slices for a perfect coronal view prior to taking measurements. In the present study as previously mentioned, each subject’s CT slices were first reoriented in Osirix using 3D MPR to obtain a coronal slice in perfect orientation. This could have contributed to differences in linear measurements that Rai et al. (2016) used to perform descriptive analysis upon in order to design the formulas used in their study, as well as the present study.

Formula application of the present study may also differ from the replicated study of Michel et al. (2016). Within the article, the presented formulas differed from coefficients stated within the article text. The coefficients within the text were -2.759, and -1.275 for the male and female groups respectively. This compares to the coefficients presented in the formula of -2.763 and -1.283 for the male and female groups respectively. The present study used the coefficients presented within the formulas for their results. However, the data were also ran with the coefficients presented in the text, and with the present study’s raw data, no difference was obtained. The raw data from Rai et al. (2016) was not given, so it is unclear whether this could have an effect on the results obtained in their study.
Furthermore, there were differences in the data analysis between the present study, and those replicated. Both Michel et al. (2015) and Rai et al. (2016) performed t-tests during their data analysis, but neither discussed performing normality tests prior to determine whether parametric testing was appropriate. In the present study, normality tests were performed on all data sets prior to the performance of a parametric or nonparametric testing. Without access to the replicated study’s raw data, it is unclear if this would influence their results. Also, the method of statistical analysis differed from the present, and replicated studies. The current study focused solely on determining whether there was a significant difference in parameters of the frontal, or maxillary sinus between sexes, whereas Michel et al. (2015) performed many tests looking for a correlation, or lack thereof, between age, and values for the frontal sinus volumes. In the case of Rai et al. (2016), their statistical analysis focused more on sex determination between parameters, but performed different statistical tests on their raw data, than the current study performed.

Limitations

Limitation of the current, and replicated studies

Accuracy rates of both the replicated frontal sinus study (Michel et al. 2015), and the replicated maxillary sinus study (Rai et al. 2016) obtained significantly higher accuracy rates with their study populations. However, these studies used one sample to obtain measurements, and construct formulae from, as well as test suggested formulae
with. This could be a limitation with the replicated studies, and potentially explain the vast difference between their obtained results, comparatively to the current study. Testing the designed formulas on the same sample study, versus a new sample, could limit the validity of their obtained accuracy results. As previously mentioned, the observation of a statistically significant difference between the frontal sinus volumes of data set one, and data set two should be considered a severe limitation of the current study. The possibility of measurement error should be considered when referencing the results of the current study. A second limitation of the current study would be observed in the small sample size. Availability of CT scans at the current institution limited the options of larger sample sizing.
Chapter 5: Conclusion

This study was designed in an attempt to replicate and verify results of two previous studies, in order to determine which paranasal sinus identified sex of an unknown individual with the highest accuracy rates. Through the application of the methods previously stated in this study, it was determined that in the given sample, the right maxillary sinus formula resulted in the highest accuracy rates of sex identification. These being 60.00% in the male sample, and 62.90% in the female sample for an overall accuracy of 61.40%. This accuracy rate was found to be relatively low compared to other studies on the maxillary and frontal sinus’ as well as a relatively low accuracy rate compared to other methods of identification. It is not believed that this study has concluded either sinus to be a preferred method of sex identification, and should only be used when other methods of sex identifications have been exhausted, and produced no results.

Addressing the research questions previously stated in the aims of this study,

- Significant intra-observer error was identified in measurements of the total frontal sinus volume.
No significant sex differences were identified in frontal sinus volumes.

Overall accuracy rates for the frontal sinus was only 59.60%, a value significantly lower than the replicated study’s accuracy rate of 72.50% (Michel et al. 2015).

No significant differences were found between the right and left sinus parameters in either the male or female samples.

No significant difference between the sexes in the maxillary sinus volumes, while weak statistically significant differences were found in the linear parameters.

The accuracy rates of the current maxillary sinus study varied from 61.40% for the right maxillary sinus formula, 52.60% for the left maxillary sinus formula, and 47.38% for the combined maxillary sinus formula. All of which were relatively lower than the replicated study at 80.00%, 73.30%, and 83.30% respectfully (Rai et al. 2016).
References


