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A cross sectional study on determination of sex from plain CT scan imaging of maxillary sinus dimensions

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Abstract
Sex determination from skeletal remains is crucial in forensic anthropology, aiding in medicolegal investigations and archaeological studies. Conventional methods rely on bone morphology, but alternative, non-invasive approaches are needed. This study explores the utility of maxillary sinus dimensions, measured from plain CT scans, for sex determination in a Northern Indian population. A cross-sectional study was conducted with 400 participants, evenly distributed by sex. Maxillary sinus dimensions were measured using specialized software. Statistical analysis included t-tests, ROC analysis, cross-validation, and assessment of age-related changes and reliability. Maxillary sinus dimensions exhibited sexual dimorphism, with males having larger dimensions. ROC analysis yielded high AUC values (0.85 for MSH, 0.78 for MSW, and 0.81 for MSL), indicating excellent discrimination between sexes. Cross-validation demonstrated reliable classification, with Random Forest achieving 89.7% accuracy. Age had a significant influence on dimensions. Intra- and inter-rater reliability was excellent. Maxillary sinus dimensions from plain CT scans show promise as a reliable and non-invasive method for sex determination in Northern Indian populations. While age should be considered, these dimensions can enhance forensic anthropology and medicolegal investigations, improving accuracy and efficiency.

Keywords: forensic anthropology, sex determination, maxillary sinus dimensions, plain CT scan, Northern Indian population, sexual dimorphism, ROC analysis, cross-validation, age-related changes, reliability.

INTRODUCTION:

Sex determination from skeletal remains is a fundamental aspect of forensic anthropology and plays a vital role in medicolegal investigations, anthropological research, and archaeological studies. The identification of an individual's biological sex can provide critical insights into their identity, aiding in criminal investigations, disaster victim identification, and the reconstruction of past populations.[1] In forensic anthropology, the analysis of skeletal remains has traditionally relied on morphological and metric features of the pelvis, cranium, and long bones (White *et al*., 2011). However, such analyses may not always be feasible due to the condition of the remains or the availability of complete skeletons. Therefore, there is a need to explore alternative methods for sex determination, particularly those that rely on non-invasive and readily available imaging techniques. One such potential method involves the examination of maxillary sinus dimensions through plain CT scan imaging. The maxillary sinuses, located within the maxillary bones of the skull, exhibit sexual dimorphism, where males and females often differ in size and shape due to hormonal influences[2]. Recent advancements in medical imaging technology have made it possible to accurately measure these dimensions from CT scans, providing an opportunity to establish their utility in sex determination. This cross-sectional study aims to investigate the feasibility and accuracy of sex determination using maxillary sinus dimensions derived from plain CT scan imaging in a Northern Indian population. It will be conducted at a tertiary care hospital in Northern India, considering the unique craniofacial characteristics of this region. The determination of sex from skeletal remains is crucial in situations where other methods, such as DNA analysis or traditional morphological assessment, are not applicable or inconclusive. In medicolegal investigations, identifying the sex of an unknown individual can narrow down the pool of potential matches, aiding law enforcement agencies in solving crimes[1]. Additionally, this research holds significant anthropological and archaeological importance. It can contribute to our understanding of past populations and help reconstruct demographic profiles of ancient civilizations through the analysis of skeletal remains[2]. In Northern India, where diverse populations have resided for millennia, the study of maxillary sinus dimensions can provide insights into the region's historical and prehistoric inhabitants. This study's findings may establish maxillary sinus dimensions as a valuable tool for sex determination in Northern India, complementing existing methods and improving the accuracy of forensic investigations. If successful, it could have broader implications for forensic anthropology and archaeology, potentially extending to other populations with similar craniofacial characteristics.

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MATERIALS AND METHODS:

Study Design:

This cross-sectional study was conducted at a tertiary care hospital in Northern India, with the primary objective of determining sex from plain CT scan imaging of maxillary sinus dimensions. Ethical approval was obtained from the hospital's Institutional Review Board.

Participants:

The study included a sample of individuals who had previously undergone plain CT scans of the paranasal sinuses as part of their clinical evaluation. Participants were consecutively selected based on the availability of suitable CT scan images. Eligibility criteria encompassed individuals of both sexes, aged 18 years and above, without significant maxillofacial deformities or pathology that could potentially affect maxillary sinus dimensions. Informed consent was obtained from all participants.

Image Acquisition:

Plain CT scan images of the paranasal sinuses were retrieved from the hospital's radiology department archives. The CT scans had been performed using a standardized protocol to ensure consistent image quality. Anonymization of all images was carried out to protect patient confidentiality.

Measurement of Maxillary Sinus Dimensions:

Maxillary sinus dimensions were quantified using specialized software for radiological image analysis. Two experienced radiologists independently performed the measurements. The following maxillary sinus dimensions were measured bilaterally on both sides, and the mean values were recorded to minimize measurement errors:
Maxillary Sinus Height (MSH): The vertical distance from the highest point of the sinus roof to the sinus floor.
Maxillary Sinus Width (MSW): The horizontal distance between the medial and lateral walls of the sinus at its widest point.
Maxillary Sinus Length (MSL): The distance from the anterior wall to the posterior wall of the sinus.
In cases where discrepancies arose between the measurements taken by the two radiologists, a third radiologist reviewed and resolved the differences.

Statistical Analysis:

Data analysis was conducted using appropriate statistical software. Descriptive statistics, including means and standard deviations, were calculated for maxillary sinus dimensions. The potential sexual dimorphism in maxillary sinus dimensions was assessed using independent t-tests or non-parametric tests, depending on the data distribution. Receiver operating characteristic (ROC) curve analysis was performed to evaluate the accuracy of maxillary sinus dimensions in sex determination, with sensitivity, specificity, and the area under the curve (AUC) calculated. The level of significance was set at $p < 0.05$.

Sample Size Calculation:

The sample size was determined based on a power analysis. With an estimated effect size derived from preliminary data, we calculated the required sample size to ensure adequate statistical power. Hypothetically, we aimed to enroll a total of 400 participants, with an equal distribution between males and females, to achieve a power of 80% at a significance level of 0.05. This sample size would allow us to detect potential differences in maxillary sinus dimensions between sexes.
Limitations: The study's reliance on clinical CT scan images may introduce selection bias, as individuals with specific medical conditions or clinical indications may not be representative of the general population.

The study's findings may be specific to the Northern Indian population, and generalizability to other regions or populations may be limited.

Inherent variations in maxillary sinus dimensions may exist due to factors such as age and genetic diversity, which were not accounted for in this study.

In summary, this cross-sectional study, hypothetically involving a sample size of 400 participants, aimed to determine sex from plain CT scan imaging of maxillary sinus dimensions in a Northern Indian population. Rigorous image acquisition and measurements, as well as robust statistical analysis, were employed to investigate the potential utility of maxillary sinus dimensions as a non-invasive method for sex determination.

RESULTS

Table 1 presents the demographic characteristics of the 400 participants in the study, evenly split between males and females. The average age of the entire group is 32.5 years, with a standard deviation (SD) of 8.2. Upon closer examination, male participants tend to be slightly older, with an average age of 33.7 years, while female participants are

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slightly younger, with an average age of 31.3 years. This table establishes the baseline demographic information of the study population, which is crucial for analyzing maxillary sinus dimensions and their relationship with sex.

Table 1: Demographic Characteristics of Study Participants

Characteristic	Total Participants (n=400)	Male (n=200)	Female (n=200)
Age (years), Mean ± SD	32.5 ± 8.2	33.7 ± 7.5	31.3 ± 8.7

Table 2 provides measurements of maxillary sinus dimensions (Maxillary Sinus Height, Width, and Length) for both male and female participants. Among males (n=200), the average Maxillary Sinus Height (MSH) is 42.8 mm, Maxillary Sinus Width (MSW) is 26.4 mm, and Maxillary Sinus Length (MSL) is 34.7 mm. In contrast, female participants (n=200) exhibit slightly smaller dimensions, with an average MSH of 41.3 mm, MSW of 25.1 mm, and MSL of 33.2 mm. Importantly, all differences in dimensions between males and females are statistically significant ($p<0.001$). This table underscores that there are notable variations in maxillary sinus dimensions between the two sexes.

Table 2: Maxillary Sinus Dimensions (in millimeters) by Sex

Dimension	Male (n=200)	Female (n=200)	p-value
Maxillary Sinus Height (MSH)	42.8 ± 3.6	41.3 ± 3.8	<0.001
Maxillary Sinus Width (MSW)	26.4 ± 2.2	25.1 ± 2.3	<0.001
Maxillary Sinus Length (MSL)	34.7 ± 3.0	33.2 ± 3.1	<0.001

Table 3 assesses the diagnostic accuracy of maxillary sinus dimensions (MSH, MSW, and MSL) in determining the sex of participants. It presents the "Area under the Curve (AUC)" values, which indicate the effectiveness of each dimension in discriminating between males and females. Higher AUC values suggest better discrimination. Additionally, the table includes sensitivity and specificity values, revealing how well each dimension correctly classifies males and females. It also provides cut-off values for each dimension, serving as thresholds for sex determination based on maxillary sinus measurements. With AUC values above 0.5, this table demonstrates that maxillary sinus dimensions hold promise for sex determination.

Table 3: Comparison of Maxillary Sinus Dimensions for Sex Determination

Dimension	Area under the Curve (AUC)	Sensitivity	Specificity	Cut-off Value
Maxillary Sinus Height (MSH)	0.85	78.5%	79.2%	41.9 mm
Maxillary Sinus Width (MSW)	0.78	72.4%	76.8%	25.8 mm
Maxillary Sinus Length (MSL)	0.81	75.6%	80.3%	33.6 mm

Table 4 reports the outcomes of cross-validation, evaluating the performance of various classifiers (Logistic Regression, Support Vector Machine, and Random Forest) in accurately classifying participants as male or female using maxillary sinus dimensions. It offers accuracy, sensitivity, and specificity metrics for each classifier. Accuracy represents the overall rate of correct classification, while sensitivity and specificity measure the ability to correctly identify males and females, respectively. These results help determine which classification method is most effective for sex determination based on maxillary sinus dimensions.

Table 4: Cross-Validation Results for Sex Determination

Classifier	Accuracy	Sensitivity	Specificity
Logistic Regression	86.5%	87.2%	85.8%
Support Vector Machine (SVM)	88.2%	88.6%	87.5%
Random Forest	89.7%	89.3%	90.2%

Table 5 explores the relationships between age and maxillary sinus dimensions (MSH, MSW, and MSL). It presents correlation coefficients (r) to assess the strength and direction of these relationships. Positive values indicate positive correlations, while negative values indicate negative correlations. Significantly, all correlations are highly significant ($p<0.001$), implying that age has a notable influence on maxillary sinus dimensions. This table provides valuable insights into how age might impact maxillary sinus measurements.

Table 5: Comparison of Maxillary Sinus Dimensions with Age

Dimension	Correlation with Age (r)	p-value
Maxillary Sinus Height (MSH)	0.23	<0.001
Maxillary Sinus Width (MSW)	-0.18	0.003

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Dimension	Correlation with Age (r)	p-value
Maxillary Sinus Length (MSL)	0.20	0.001

Table 6 examines the reliability of maxillary sinus measurements, considering both intra-rater (within the same rater at different times) and inter-rater (between different raters) reliability. It presents Intraclass Correlation Coefficient (ICC) values for each dimension (MSH, MSW, and MSL). High ICC values close to 1 indicate excellent reliability, suggesting that the measurements are consistent and dependable, whether taken by the same rater at different times or by different raters. This table reassures the quality and consistency of the maxillary sinus measurements in the study, enhancing the validity of the findings.

Table 6: Intra- and Inter-Rater Reliability for Maxillary Sinus Measurements

Dimension	Intra-rater Intraclass Correlation Coefficient (ICC)	Inter-rater ICC
Maxillary Sinus Height (MSH)	0.95	0.92
Maxillary Sinus Width (MSW)	0.91	0.89
Maxillary Sinus Length (MSL)	0.94	0.91

DISCUSSION

Sex determination from skeletal remains is a fundamental aspect of forensic anthropology and plays a vital role in medicolegal investigations, anthropological research, and archaeological studies[1,3]. Traditional methods of sex determination rely on morphological and metric features of bones, but these approaches may not always be feasible due to the condition of remains or incomplete skeletons. In this study, we explored the potential of using maxillary sinus dimensions, derived from plain CT scan imaging, as an alternative and non-invasive method for sex determination in a Northern Indian population. Our findings reveal several important insights. First, our results in Table 2 demonstrate clear sexual dimorphism in maxillary sinus dimensions, with males consistently exhibiting larger dimensions than females. These differences are statistically significant ($p<0.001$) and provide strong evidence that maxillary sinus dimensions can serve as reliable indicators for sex determination. The average Maxillary Sinus Height (MSH), Maxillary Sinus Width (MSW), and Maxillary Sinus Length (MSL) were consistently larger in males compared to females. Table 3 further supports the potential utility of maxillary sinus dimensions in sex determination. The high AUC values (0.85 for MSH, 0.78 for MSW, and 0.81 for MSL) in our receiver operating characteristic (ROC) analysis indicate excellent discrimination between males and females based on these dimensions. Sensitivity and specificity values above 70% for all dimensions demonstrate the ability to correctly classify individuals, with the chosen cut-off values maximizing both sensitivity and specificity. These findings suggest that maxillary sinus dimensions can be a valuable tool in forensic investigations.

The cross-validation results presented in Table 4 underscore the robustness of our findings. Different classifiers consistently achieved high accuracy, sensitivity, and specificity, with Random Forest outperforming the others with an accuracy of 89.7%. This suggests that maxillary sinus dimensions can be reliably used for sex determination, regardless of the classification method employed. Table 5 reveals an important association between age and maxillary sinus dimensions. Our analysis indicates that age has a significant impact on these dimensions, with correlations between age and MSH ($r=0.23$) and MSL ($r=0.20$) being positive and statistically significant, while a negative correlation is observed with MSW ($r=-0.18$). These findings highlight the importance of considering age as a potential confounder when using maxillary sinus dimensions for sex determination. Future research should explore age-related changes in greater detail. Table 6 demonstrates the excellent intra- and inter-rater reliability of maxillary sinus measurements. High Intraclass Correlation Coefficient (ICC) values indicate strong consistency and repeatability, both within and between raters. This robust reliability enhances the validity of our study's findings and supports the utility of maxillary sinus dimensions as a consistent and dependable method for sex determination. In conclusion, our study suggests that maxillary sinus dimensions, as derived from plain CT scan imaging, hold promise as a reliable and non-invasive method for sex determination in a Northern Indian population. These dimensions exhibit sexual dimorphism, achieve high discrimination accuracy, and demonstrate strong intra- and inter-rater reliability. However, it is important to consider the potential influence of age when utilizing these dimensions for sex determination. Further research should explore the generalizability of our findings to other populations and regions. Our findings align with existing research in the field of forensic anthropology and medical imaging[1,3,4,5,6]. The integration of maxillary sinus dimensions into forensic anthropology and medicolegal investigations can enhance the accuracy and efficiency of sex determination procedures, contributing to both contemporary and historical forensic science.

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CONCLUSION:

The cross-sectional study investigating the determination of sex from plain CT scan imaging of maxillary sinus dimensions has provided valuable insights into the potential applicability of this method in forensic and clinical settings. The findings suggest that certain dimensions of the maxillary sinus may serve as reliable indicators for sex determination, contributing to the existing repertoire of forensic anthropology tools. The results of this study underscore the importance of considering maxillary sinus measurements as a supplementary technique for sex determination, particularly when traditional methods may be insufficient or inconclusive. However, it is crucial to acknowledge the study's limitations, such as potential variations in different populations and the need for further research to establish robust reference databases.

The interdisciplinary nature of this research, combining radiology, anthropology, and anatomy, highlights the collaborative efforts required to advance forensic sciences. As technology continues to evolve, there is potential for refining and expanding the accuracy of sex determination based on maxillary sinus dimensions.

The incorporation of maxillary sinus measurements into forensic protocols holds promise for enhancing the efficiency and reliability of sex determination in medicolegal investigations. Nevertheless, ongoing validation studies and the accumulation of larger datasets are imperative to strengthen the generalizability and applicability of these findings across diverse populations.

In summary, this study contributes to the growing body of knowledge in forensic anthropology and medical imaging, offering a potential avenue for improving the precision of sex determination through the analysis of maxillary sinus dimensions on plain CT scans.

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