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Artificial Neural Network as a Predictive Tool for Gender Determination using Volumetric and Linear Measurements of Maxillary Sinus CBCT: An Observational Study on South Indian Population

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ABSTRACT

Introduction: Determination of age and gender using bones of skull is central aspect of forensic odontology. Maxillary sinuses in this regard have shown high accuracy in predicting gender.

Aim: To identify gender using the volumetric and linear measurements of maxillary sinuses obtained from a Cone Beam Computed Tomography (CBCT) by using Artificial Neural Network (ANN) based tool.

Materials and Methods: A retrospective observational study was conducted on 80 volumes of CBCT (derived from n=80 patients) with equal gender distribution. The CBCT images were analysed for eight linear and two volumetric measurements namely the maxillary sinus height, maxillary sinus length, maxillary sinus width, distance between infraorbital foramen and distance between maxillary sinus. The data from these parameters were reported by two experts and subjected to discriminant analysis and McNemars test for gender determination. The same data was also fed to the ANN software and the accuracy of its gender prediction was analysed by Receiver Operating Characteristics Curve (ROC) and Area Under the Curve (AUC).

Results: The ROC test and AUC (ANN-Test) had shown high accuracy for prediction of gender form the data of the CBCT parameters for maxillary sinuses. McNemars test showed that the difference in proportion between the actual gender and ANN predicted gender was not significant (p-value=0.687) and the agreement between the actual gender and ANN in measuring the gender was 84.6%. The male sex was predicted correctly upto 89.7% and female sex upto 94.9%.

Conclusion: This study has found ANN to have an encouraging predictive power in gender determination based on linear and volumetric measurements of maxillary sinus obtained from CBCT.

Keywords: Cone beam computed tomography, Forensic odontology, Gender assessment

INTRODUCTION

The gender assessment establishes a vital step in constructing a postmortem profile and it is a distinctive procedure in Forensic Medicine [1]. Mutilated corpses beyond recognition are commonly presented to investigators where gender determination becomes the first element to establish an identity. The identification of bones of the skull is reported to show accuracy upto 90% in gender determination [2]. The skull is the second most common osseous structure (after pelvis) used in forensic investigations as it is well preserved after death [3]. The zygomatic and maxillary bones are reported to stay intact even after the incineration [4]. Maxillary bones contain prominent air spaces/cavity called as maxillary sinuses which can be of various sizes and shapes. They start appearing at the end of the second embryonic month and attain their maturity at the age of 20 years (i.e. when the permanent teeth are fully developed) and, tend to stabilise after the second decade of life. The difference in size and shapes of the maxillary sinus accounts for the dimorphic feature between the sexes. The exact measurements of the maxillary sinus is a key to establish the dimorphic difference which could be accomplished by the modern age technology. The CBCT is a dedicated imaging modality available to image exclusively the boundaries of soft tissues and sinuses accurately. It is employed for differentiating gender measuring anatomical landmarks [4,5].

The CBCT offers three dimensional (3D) images being acquired on isotropic voxels simulating the anatomical structures. The embedded software system of CBCT device is reported to provide accurate measurements on both linear and volumetric fronts [4,6]. As such, the 3D imaging modalities have a significant role in determination of anatomical landmarks. [7,8]. Artificial Intelligence (AI) is a growing technology and has already lanced a large part of our everyday life [9]. The ANN one of the analysis tools has been used in forensic sciences to predict age and gender using the skeletal bone metrics [1]. There is very little literature with regard to gender determination using indices of the maxillary sinus from a CBCT. The current study was aimed at determining the accuracy of predicting gender using ANN tool from the data obtained out of volumetric and linear measurements of maxillary sinus on the CBCT images.

MATERIALS AND METHODS

A retrospective observational study was carried out from 1st October 2020-15th November 2021. The analysis of the data was done from December 2021- February 2022. The proposed study was approved by the Institutional Ethical Committee (IEC) [Reference number: IGIDSIEC2020NRP52PGPDOMR] prior to the commencement of the study.

Inclusion criteria: The CBCT images of patients who have visited the Dental Radiology Centres in the age group of 20-70 years, who gave consent were included in the study.

Exclusion criteria: Those patient CBCT images with large craniofacial asymmetries involving the maxillary sinus/absence of any posterior teeth in the maxilla/known history of paranasal sinus surgery/known history of maxillofacial trauma (involving the maxillary sinus) were excluded. Also, those CBCT images of patients with history of pathological processes in the maxillary sinuses (chronic sinusitis or mucus retention phenomenon, odontogenic cysts), images with artefacts (impairing the complete visualisation of the maxillary sinuses), scans not covering the entire extent of the sinus were excluded from the study.

Sample size calculation: The sample was determined by using the below formula keeping the significance alpha (a)=0.05, estimated proportion (p)=0.71, estimated error (d)=0.1, and prevalence (p)=94 taken with reference to previous study [8]; the sample size was determined to be 80 using the formula,

$$n \geq \frac{Z^2_{1-\alpha/2} \times p(1-p)}{d^2} = \frac{(0.05)^2_{(1-0.05)/2} \times 94(1-0.71)}{0.1^2} = 80.613$$

Or n=80 (rounded off value).

The procedure involved CBCT images made under a continuous scan mode with the following specifications: scanning time: 28 seconds (±10%), Voxel size (μm): 500, Field of view (cm): 10×10, 17×6, 17×11, 17×13.5, Reconstruction time: <2 minutes based on the recommended computer system configuration requirements. The parameters such as Tube voltage: 90 kV, Tube current: 15 mA, Frequency: 140 kHz, Tube focal spot: 0.7 mm (IEC 60336), Input voltage (AC): 110V and Weight: 160 kg (353 lb.) were also kept constant for the entire sample. The CS 3D Imaging software (version 3.5.7, Carestream Health Inc.) and ITK SNAP software (version-3.8.0) were used in the study. The visualisation and measurements were read on a desktop [System: Intel(R) Core(TM) i3-7100U CPU @ 2.40 GHz 2.40 GHz; Hard Disk: 500 GB; Monitor: LCD; Ram: 4.00 GB (3.87 GB usable); Operating system: Windows 10 Pro Coding Language: JAVA; Tool: Eclipse IDE was used. A senior software application developer had conducted the testing of the said ANN software.

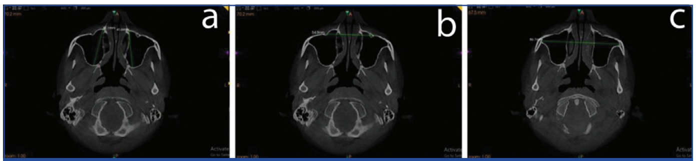
Study Procedure

Data analysis for linear measurements: Two experienced Oral Radiologists (Associate Professors in the field had viewed simultaneously) evaluated the eight linear and two volumetric measurements of maxillary sinus CBCT images. The study volumes of CBCT multiplanar reconstruction were obtained on Carestream CS 9300 and evaluated on software version 3.5.7.0 on LCD (Liquid Crystal Display) monitor with present resolution of 1920×1080 pixels. Each CBCT volume was oriented with the software vertical reference line perpendicular to the ground in the mid sagittal plane, and the horizontal reference line parallel to the ground in the axial and sagittal sections. The following measurements were recorded:

1. **Maxillary sinus height-** The distance between the lowest point of the inferior wall and the highest point of the superior wall of the maxillary sinus.
2. **Distance between the infraorbital foramen-** The distance between the right infraorbital foramina's maximum aperture to the left infraorbital foramina's maximum aperture.
3. **Distance between the maxillary sinuses-** The distance between the outermost point of the right maxillary sinus lateral wall and the outermost point of the left maxillary sinus lateral wall.
4. **Maxillary sinus length-** The distance between the most anterior point of the anterior wall of the maxillary sinus and the most posterior point of the posterior wall of maxillary sinus.
5. **Maxillary sinus width-** The distance between the lateral wall of maxillary sinuses outermost point and the medial wall's most medial point in the maxillary sinus.

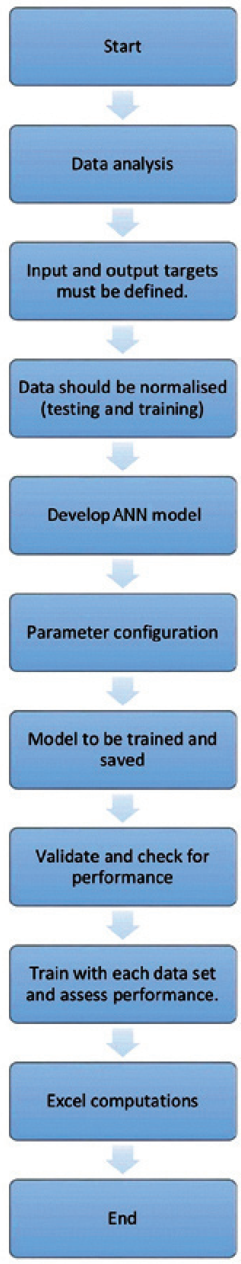
   Largest of these measurements were used in the study to determine gender. These measurements were tabulated on excel sheet which were further utilised as data feed to the ANN on the AI platform.

The volumetric measurements were acquired using ITK SNAP version 3.0 by automatic segmentation. The process involved determining the threshold interval, seeding and segmentation evolution. The threshold interval was between -1000 on the lower end to a -650 on the upper end. This determines the starting and ending of the segmentation process where all the voxels with grey values within the interval are utilised to construct the 3D model. Next seeds were placed in the Region of Interest (ROI) to initialise the segmentation process. Finally, the segmentation evolution was run by selecting the velocity and end process. Finally, the 3D reconstruction of the segmented maxillary sinus and its volume in cubic mm^3 was derived [Table/Fig-1].



[Table/Fig-1]: a) Maxillary sinus height; b) Measurement of the distance between the infraorbital foramen; c) Measurement of the distance between the maxillary sinuses on CBCT images.

Designing and programming of ANN: Designing ANN model has following systematic procedures. These include data collection and preprocessing to predicted output as shown in flow chart [Table/Fig-2]. A feed forward ANN with backpropagation technique involving one input layer (10 nodes), one hidden layer (three nodes) and one output layer (two nodes) was designed. The back



[Table/Fig-2]: Flow chart for methodology.

propagation feature of ANN allows the process to learn and evolve from the data fed to it. The input layer feed was eight linear and two volumetric data obtained from all the CBCT samples. The hidden layers processes this data and gives an output, if a mismatch in the output is evident the backpropagation technique triggers another process in the nodes of hidden layer by adjusting the numerical weights and bias till the actual result is derived (Levenberg-Marquardt optimisation). This is training and validation of the ANN. Finally, testing involves the actual process of running the samples and obtaining the results.

STATISTICAL ANALYSIS

All the statistical analysis was carried out using Statistical Package for the Social Sciences (SPSS) software (Version 22.0, IBM Corp, USA). The inter-observer variability was evaluated using Intra Class Correlation coefficient (ICC) for the entire study sample. The student's t-test was performed for comparisons of age parameters. The ROC was plotted and AUC was determined to identify the best predictor of gender amongst the CBCT parameters of maxillary sinus.

The discriminant analysis was performed to examine the significant differences which existed in predicting gender by the predictor variables. The contribution of each variable in predicting gender and accuracy of the model towards gender prediction was analysed. Gender was taken as criterion variables (male/female) and the predictor variables were sinus metrics/parameters measured on CBCT. Canonical Discriminant Function Coefficients explain the unique contribution of independent variables to the discriminate function. Hence, the equation was written as "Discriminant function= -16.19+0.245×distance between the maxillary sinus-0.14×Left maxillary sinus length+0.054×Left maxillary sinus height+0.012×Right maxillary sinus height-0.009×Right maxillary sinus length."

The structure matrix shows the relative importance of the predictors in the model in terms of correlations of each variable with the discriminate function. In this analysis, 0.30 was taken as cut-off between important and less important variables. The linear and volumetric measurements were subjected for gender predictions with ANN. An ROC/AUC recorded the distance between the maxillary sinuses, Right maxillary sinus height, left maxillary sinus height, left maxillary sinus length and right maxillary sinus length as the best predictors in the given order. McNemars test was carried out to find the differences between the actual gender and predicted gender by ANN.

RESULTS

The study was conducted on 80 participants with mean age of 42.3±3.45 years. The student's t-test showed significant differences between the actual genders for the stated parameters of maxillary sinus measured on CBCT [Table/Fig-3].

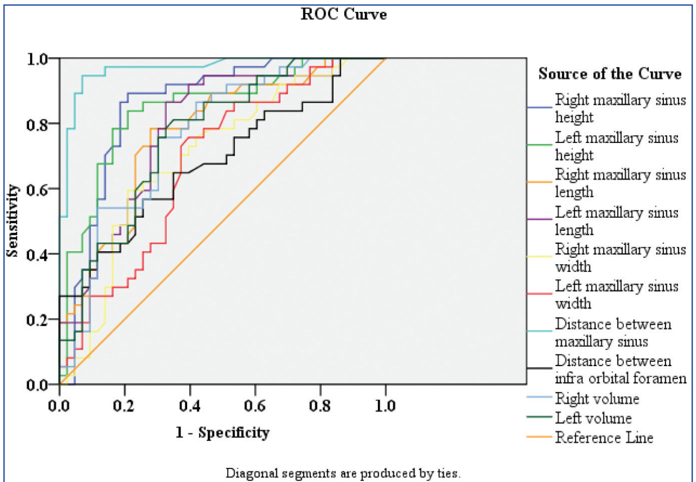
Measurements	Mean±SD	Mean actual gender		p-value
		Male (n=40)	Female (n=40)	
Right maxillary sinus height	36.8±5.0	39.04±4	34.7±5.2	0.001
Left maxillary sinus height	37.2±5.4	39.6±4.9	34.9±5	0.001
Right maxillary sinus length	39.6±4.1	40.5±5.3	38.4±4	0.058
Left maxillary sinus length	39.8±3.9	41±4	38.6±3.6	0.007
Right maxillary sinus width	31.9±4.2	32.8±3.6	31.1±4.7	0.075
Left maxillary sinus width	32.3±4.3	33.15±3.9	31.4±4.5	0.080
Distance between the maxillary sinuses	80.5±8.7	87.5±6	73.5±2.3	0.001
Distance between the infra orbital foramen	56.8±4.8	58±5.6	55.5±3.6	0.020
Right maxillary sinus volume	16498.3±5474	18005.7±5290.8	14990.9±5295.7	0.013
Left maxillary sinus volume	15977.8±5408.2	17529.5±5706.8	14426.2±4662.7	0.009

[Table/Fig-3]: The differences between the actual genders for the parameters of maxillary sinus measured on CBCT (N=80).

ICC recorded an excellent correlation between the evaluators which had an agreement with the maxillary sinus height (0.969, p<0.001), length (0.959, p<0.001), distance between the maxillary sinus (0.96, p<0.001), maxillary sinus width (0.96, p <0.001) and maxillary sinus volume (1, p<0.0001) followed by good agreement with infra-orbital foramen 0.766 (p=0.001).

The canonical discriminant function coefficients shows that the distance between the maxillary sinuses contributed high in predicting gender followed by left maxillary sinus length and rest of the variables are very meagre. In the structure matrix table, the correlations are arranged by absolute size and concluded that distance between maxillary sinuses have the highest correlation in predicting gender when compared with other predictors. Accuracy of determining sex was done based on original gender cases 96.3%.

The ROC test and AUC (ANN-TEST) had shown high accuracy for prediction of gender form the data of the CBCT parameters for maxillary sinuses [Table/Fig-4,5]. The values fed to ANN software after obtaining from CBCT and the prediction after entering these values by the software/ANN tool is shown in [Table/Fig-6].



[Table/Fig-4]: ROC curve for ANN testing: The data shows high accuracy for gender prediction by ANN tool for fed data of MS metric obtained on CBCT images.

Parameters of MS on CBCT	Function
Distance between the maxillary sinus	0.910
Right maxillary sinus height	0.277
Left maxillary sinus height	0.275
Left maxillary sinus length	0.184
Right maxillary sinus length	0.181

[Table/Fig-5]: The data obtained on Structure Matrix (canonical discriminant function coefficients).

McNemars test showed that the difference in proportion between the actual gender and ANN predicted gender was not significant (p=0.687) and the agreement between the actual gender and ANN in measuring the gender was 84.6%. The male sex was predicted correctly upto 89.7% and female sex upto 94.9% [Table/Fig-7].

DISCUSSION

Gender determination based on skeletal remains is a due challenge to date in forensic medicine. Determining sex from skull is reliable only after adolescence as there would be hormonal influences on

Test result variable (s)	Area	Standard error	Asymptotic significance	Asymptotic 95% Confidence interval	
				Lower bound	Upper bound
Distance between the maxillary sinuses	0.968	0.018	0.001	0.926	1.000
Right maxillary sinus height	0.855	0.044	0.001	0.768	0.942
Left maxillary sinus height	0.845	0.045	0.001	0.756	0.933
Left maxillary sinus length	0.784	0.052	0.001	0.683	0.886
Right maxillary sinus length	0.771	0.053	0.001	0.667	0.874
Right maxillary sinus volume	0.766	0.053	0.001	0.662	0.870
Left maxillary sinus volume	0.766	0.052	0. 001	0.663	0.869
Right maxillary sinus width	0.699	0.059	0.002	0.583	0.815
Distance between the infra orbital foramen	0.684	0.060	0.005	0.566	0.801
Left maxillary sinus width	0.678	0.060	0.006	0.561	0.796

[Table/Fig-6]: AUC analysis for MS parameters obtained from CBCT fed to ANN tool.

Gender		ANN test set		Total
		Male	Female	
Male	Count	35	5	40
	% within gender	89.7%	10.3%	100.0%
Female	Count	3	37	40
	% within gender	5.1%	94.9%	100.0%
Total	Count	37	43	80
	% within gender	47.4%	52.6%	100.0%

[Table/Fig-7]: The accuracy of gender prediction of test set by ANN tool.

the skeletal morphology [10]. Identification and sex determination are difficult duties in explosions, combat, and other mass calamities like as plane accidents [11,12]. Although skull undergoes sufficient changes in its morphology postmortem, the sinuses remain intact to a great extent and maxillary sinuses are well preserved in most case scenarios [13,14].

The current study was a retrospective analysis of, 80 CBCT images for data on maxillary sinus metrics used to determine gender variations. These observations of maxillary sinus height were in accordance with the study conducted by Abd-alla MA and Mahdi AJ [15] who reported the mean maxillary sinus height of males to be (35.1±3.9 mm) and female maxillary sinus height (30.8±3.6 mm); Urooge A and Patil BA study showed [16] right male maxillary sinus height (35±5.3 mm), left male maxillary sinus height (35.6±5.7 mm) and female right maxillary sinus height (34±4.4 mm), female left maxillary sinus height (33.8±4.8 mm); Gomes FA et al., [8] reported right male maxillary sinus height (43.5±0.77 mm), left male maxillary sinus height (43.5±0.78 mm) and right female maxillary sinus height (38.4±0.59 mm), left female maxillary sinus height (38.0±0.63 mm). Kandel S et al., had performed a similar morphometric analysis where in the discriminative analysis showed that the accuracy of maxillary sinus measurements was 72.5% in females and 75% of males [17]. Hettiarachchi PV et al., [18] reported maximum male maxillary sinus height (21.4±5.42 mm), minimum male maxillary sinus height (16.43±3.75 mm) and female maximum maxillary sinus height (21.3±5.02 mm), minimum female maxillary sinus height (17.36±4.15 mm). In the above studies, the male and female maxillary sinus heights were different and statistically significant. They also reported that males had the higher values when compared to females. However, no statistical difference in height was reported by a few studies [19,20] in which the measurements were carried out on two-dimensional imaging (OPG and lateral cephalogram). This would have inherent shortcomings of accuracy in measurements. The study conducted on the conventional CT also would face similar challenge, as the voxels on conventional CT are anisometric.

A study by Paknahad M et al., reported male right maxillary sinus length 40.32±3.06 mm, male left maxillary sinus length 40.10±2.82 mm and right female maxillary sinus length and left female maxillary sinus length were 37.81±3.7 mm and 37.6±3.5 mm respectively, [21]. Tambawala SS et al., found that male right maxillary sinus length of 40.2±3 mm, male left maxillary sinus length 39.59±2.9 mm and female right male maxillary sinus length 35.6±3.8 mm, female left maxillary sinus length 35.12±3.9 mm. in these studies both right and left-side maxillary sinus length were significantly different in male and female [5].

Sharma SK et al., conducted a study using the maxillary sinus measurements for gender determination using CT in which there were no statistical significance between the male and female maxillary sinus widths [22]. A study by Tambawala SS et al., evaluated sexual dimorphism of maxillary sinus dimensions using the CBCT reported that right maxillary sinus width of male and female was 29.78±2.25 mm, 23.80±5.04 mm respectively; left maxillary sinus width of male and female was 29.75±2.39 mm, 23.61±4.24 mm respectively [5]. Uthman AT et al., reported that maxillary sinus measurements using helical CT in this study right maxillary sinus width of males and females was 24.7±4 mm; 22.7±3.2 mm, left maxillary sinus width of males and females 25.6±4.4 mm; 23±4 mm. The maxillary sinus width of male and females were significantly different in both the studies which were not in accordance with this study [23]. Ekizoglu O et al., [24] had reported, maxillary sinus measurements using the multidetector computed tomography, and found that male right and left transverse measurements of maxillary sinus was 24.5±0.3 mm and 24±0.3 mm respectively, female right and left transverse measurements in CT was 21.4 ±0.3 mm and 21.1±0.3 mm which was similar to present study.

The observations of distance between the maxillary sinus and the infraorbital foramen were in accordance with the study by Gomes FA et al., the study reported distance between the maxillary sinus 88.3±1.03 mm, 83.0±0.79 mm in males and females respectively and the distance between the infraorbital foramen in males and females was 54.7±0.54 mm, and 51.4±0.53 mm. Similar observations were reported by Uthman AT et al., that reported male distance between the maxillary sinus were 82.4±7.7 mm and female was 77.9±6.2 mm [23].

In current study, ANN had accuracy of 84.6% and with discriminant analysis original grouped cases were 96.3% while 95.0% were cross validated. Thus, the use of several variables and samples for ANN prediction improves the sensitivity and specificity of the prediction tool, according to present study findings [6]. There are numerous studies being conducted in this area to understand the ability of CBCT in sex determination in various ethnic groups [25-27]. The current study was unique for reporting data from Southern Indian population. The future directions include conduct of larger studies and to design mobile application for gender prediction.

Limitation(s)

This study has its limitations in its small sample size.

CONCLUSION(S)

The current study of predicting gender using an AI tool shows significant reliability in predicting correctly upto 89.7% male and upto 94.9% female compared to the actual gender. The ANN used linear and volumetric measurements of maxillary sinuses from the known CBCT samples as the key parameters. CBCT and prediction of gender with ANN offers a new insight in forensic odontology.

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