EGYPTIAN
DENTAL JOURNAL
www.eda-egypt.org

VOL. 69, 1145:1152, APRIL, 2023

PRINT ISSN 0070-9484 • ONLINE ISSN 2090-2360

ORAL MEDICINE, X-RAY, ORAL BIOLOGY AND ORAL PATHOLOGY

Submit Date : 13-02-2023 • Accept Date : 08-03-2023 • Available online: 01-04-2023 • DOI : 10.21608/edj.2023.193728.2440

EVALUATION OF THREE DIFFERENT FRONTAL SINUS INDEX MEASUREMENT PROTOCOLS FOR SEXUAL DISCRIMINATION AMONG EGYPTIAN ADULTS: A LATERAL CEPHALOMETRIC RETROSPECTIVE STUDY

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ABSTRACT

Objectives: To evaluate the accuracy of three different measurement protocols of frontal sinus index for sex estimation among a group of adult Egyptian population.

Methods: One hundred and seventy-five retrospective digital lateral cephalometric radiographs of adult Egyptian individuals were included in this study (eighty males and ninety-five females). The maximum height and the maximum width (measured with 3 different methods) of the frontal sinus were measured, then three frontal sinus indices (FSIs) were calculated. All the measurements were statistically analyzed.

Results: It was found that all the three FSIs calculated in this study were higher in females than in males with statistical significant difference. Moreover, using the ROC analysis, the area under the curve (AUC) of the three protocols was less than (<0.5) suggesting no discrimination. However, FSI (Protocol 1) had the highest value AUC, followed by FSI (Protocols 2 and 3).

Conclusions: Although the frontal sinus is unique for each individual, the usage of the frontal sinus index for sexual discrimination needs more investigations and research on different populations. FSI (Protocol 1) may be a promising tool for sex estimation. Its sensitivity and specificity may improve when combined with other frontal sinus morphological parameters.

KEYWORDS: Lateral Cephalometric Radiographs, Frontal Sinus Index, Sexual Discrimination, Forensic Dentistry

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INTRODUCTION

The frontal sinus is a paired, rarely symmetrical air-filled irregularly shaped cavity located in the frontal bone in the posterior part of the supercilliary arcs.[1,2] The frontal sinus has several functions including skull weight reduction as well as humidifying and regulating the air temperature.[3]

The frontal sinus is not evident at birth; its development usually starts during the second year of life, begins to be radiographically visible around the age of 5 years and its rate of growth is highest at puberty. It is widely accepted that the shape and volume of the frontal sinus become stable at the age of 20 years.[4] Afterwards, it remains constant in size; however, some enlargement may happen due to bone resorption in old age.[5, 6]

Sex determination is one of the most common applications and purposes of forensic sciences. Schuller was the first to suggest the role of frontal sinus for this purpose.[7] Because of its unique asymmetrical shape, complexity and fingerprint-like individuality, even between monozygotic twins, frontal sinus can be used for forensic personal identification and/or sex determination owing to the fact that the skull is the best preserved part of the body after death and that it comes secondary to pelvis for sex discrimination.[2,8,9]

Several radiographic imaging modalities play an important role in forensic science as they provide various morphological data as well as being an easy and accessible methods of examination.[10,11] These imaging modalities include plain X-rays, especially lateral cephalometric views[12, 13], posteroanterior views.[14, 15], Caldwell views[1, 16], computed tomography (CT)[17,18] , and more recently cone-beam computed tomography (CBCT). [1,19]

Since the introduction of cephalometric radiography by Broabdent, the use of lateral cephalometric radiographs in craniofacial research has increased. The frontal sinus is clearly identified on lateral cephalograms because of its unique shape and air-filled nature. The term “Frontal Sinus Index” (FSI) which is a ratio between the maximum frontal sinus height and anteroposterior width was developed and used as a morphometric parameter for sex discrimination on lateral cephalograms.[8]

However, on reviewing the literature, three different FSI measurement protocols were found. Each protocol has its different method in determining the frontal sinus anteroposterior width.

Therefore, this research aims to evaluate the accuracy of the three different FSI measurement protocols (based on the different anteroposterior width determination) for sex discrimination among a group of adult Egyptian population.

MATERIALS AND METHODS

This retrospective study was conducted on lateral cephalometric radiographs of 95 females and 80 males which were extracted over a period of 6 months from the database of a private maxillofacial radiology center in Cairo, Egypt. The selected scans were all for patients above 20 years (age range 20-55 years). Scans with frontal sinus abnormalities (e.g. sinusitis, agenesis, mucocele, traumatic frontal injuries, history of frontal sinus surgery… etc) as well as scans with artifacts were excluded from this study. All of the digital lateral cephalometric radiographs were taken by Pax-i3D Green cephalometric machine (Vatech, Gyeonggi-do, Korea) using the standard adult scanning protocol (80kVp, 10mA and 16.9 sec) and with the patient’s position adjusted according to the manufacturer’s recommendations. The obtained images were then exported as DICOM file format. The images were then imported to MicroDicom Viewer 2022.2 software (MicroDicom Ltd, Sofia, Bulgaria) for taking the required measurements independently by two oral and maxillofacial radiologists of more than ten years of experience after calibration and a consensus session. The two observers were blinded of both patient's sex and age as well as from each other's readings, which were concealed by a colleague who did not participate in the study.

At the beginning of the measurement process, a rectangle (yellow colored) was drawn tangent to the four borders (superior, inferior, anterior and posterior) of the frontal sinus (Fig. 1). In order to measure the frontal sinus height, a vertical line connecting the highest and lowest points of the frontal sinus was drawn (Fig. 1). For measuring the frontal sinus width, three protocols were adopted. For the first protocol, the width was measured as a diagonal line connecting the most anterior and the deepest posterior points of the sinus (Fig. 2).[20] For the second protocol, the width was taken by connecting the most anterior wall of the sinus at its deepest portion to the maximum height line through a perpendicular line reaching the posterior frontal sinus border (Fig. 3).[1,13] For the third protocol, the maximum frontal sinus width was taken perpendicular to the maximum height line (Fig. 4).[4,21] Afterwards, the frontal sinus index (FSI), which is the ratio of the measured height to the width, was calculated for the three proposed methods independently. The obtained values from both observers were then tabulated with the corresponding sex and subjected to statistical analysis.

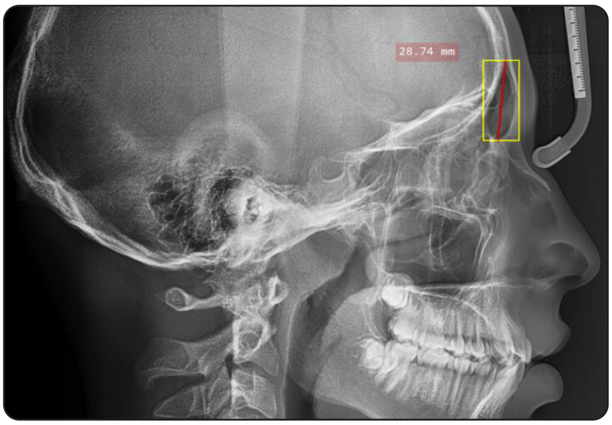

Fig. (1) Lateral cephalogram showing the rectangle (yellow) that was drawn tangent to the four borders (superior, inferior, anterior and posterior) of the frontal sinus. The maximum frontal sinus height (red line) is shown as a vertical line connecting the highest and lowest points.

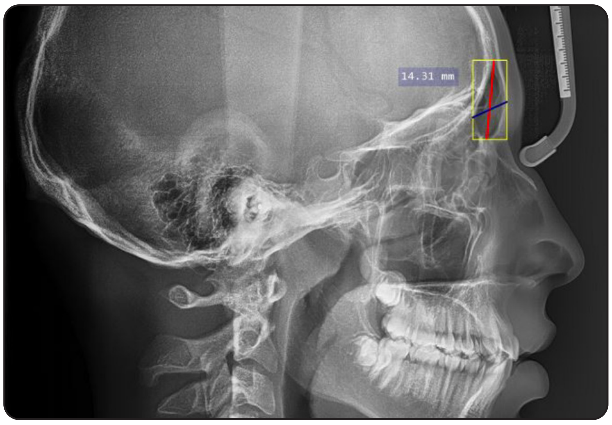

Fig. (2) Lateral cephalogram showing the first protocol for measuring the sinus width through a diagonal line connecting the most anterior and the deepest posterior points of the sinus (Blue line).

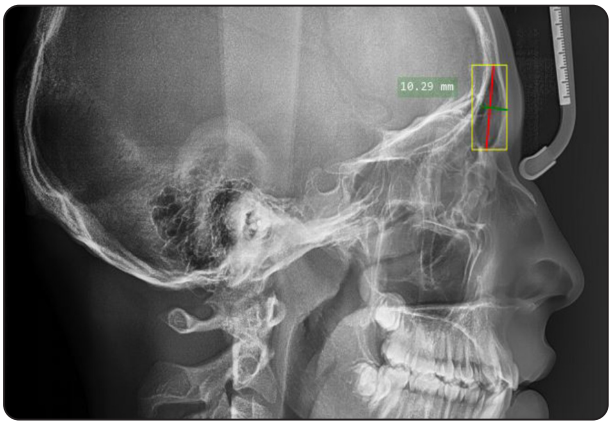

Fig. (3) Lateral cephalogram showing the second protocol for measuring the sinus width through a line connecting the most anterior wall of the sinus at its deepest portion to the maximum height line through a perpendicular line reaching the posterior border (Green line).

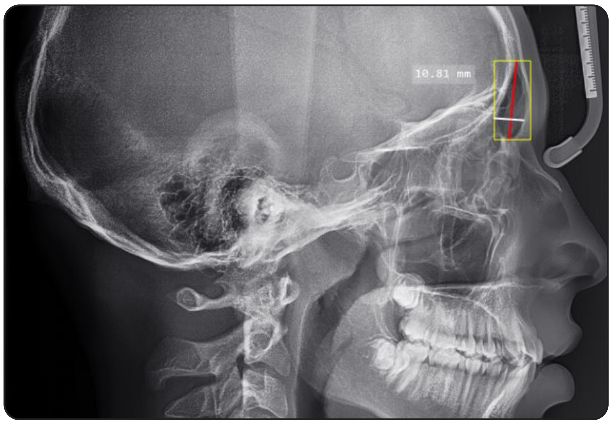

Fig. (4) Lateral cephalogram showing the third protocol for measuring the sinus width through a line corresponding to the maximum frontal sinus width perpendicular to the maximum height line (White line).

Statistical analysis:

Data management and statistical analysis were performed using the Statistical Package for Social Sciences (SPSS) version 18. Numerical data were summarized using mean, standard deviation and confidence intervals. Data were explored for normality by checking the data distribution and using Kolmogorov-Smirnov and Shapiro-Wilk tests. Comparisons between groups with respect to normally distributed numeric variables were compared using independent t test. Comparison of different methods of FSI calculation was performed by repeated measures ANOVA test. All p-values are two-sided. P-values ≤0.05 were considered significant.

RESULTS

Inter observer reliability

In order to determine the reliability and reproducibility in this study, inter-observer variation was assessed. The inter-observer analysis demonstrated an excellent correlation (ranging from 0.974 to 0.997) for all measurements, except for the width with the 3rd protocol in males, which recorded acceptable correlation (0.788) (Table 1). Therefore, the average of both examiners was used for statistical analysis.

Comparison of different FSI protocols between males and females

FSI (Protocol 1) in females (2±.53) was significantly higher than males (1.68±.31), (p=0.00). FSI (Protocol 2) in females (3.23±.87) was significantly higher than males (2.48±.66), (p=0.00). FSI (Protocol 3) in females (2.81±.63) was significantly higher than males (2.24±.47), (p=0.00) (Table 2, Fig.5).

ROC curve

The area under the curve of the three protocols was less than (<0.5) suggesting no discrimination (i.e. all three Protocols failed to act as a sex predictor). However, FSI (Protocol 1) had the highest value area under the curve (AUC), followed by FSI (Protocols 2 and 3) (Table 3, Fig. 6).

At optimal cut off values, using FSI (Protocol 1) had 57.5% sensitivity with a specificity of 24%. While, using FSI (Protocol 2) had 51% sensitivity with a specificity of 14% and using FSI (Protocol 3) had 56% sensitivity with a specificity of 15% (Table 4).

TABLE (1): Inter rater reliability analysis

Average Measures	Correlation coefficient	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	P value
Male (height)	.997	.995	.998	322.192	79	79	.000*
Male (width1)	.996	.993	.997	226.725	79	79	.000*
Male (width 2)	.974	.960	.983	38.605	79	79	.000*
Male (width 3)	.788	.669	.864	4.707	79	79	.000*
Female (height)	.984	.976	.989	63.193	94	94	.000*
Female (width1)	.988	.982	.992	82.485	94	94	.000*
Female (width 2)	.984	.976	.989	61.807	94	94	.000*
Female (width 3)	.987	.981	.991	77.806	94	94	.000*

Significance level p≤0.05, *significant

TABLE (2): Descriptive statistics and comparison between males and females (independent t test)

	Groups	Mean	Std. Dev	Std. Error Mean	Difference				t	P
					Mean	Std. error	C.I. lower	C.I. upper		
FSI (Protocol 1)	Male	1.68	.31	.03	-.320	.064	-.447	-.194	-5.00	.000*
	Female	2.00	.53	.05						
FSI (Protocol 2)	Male	2.48	.66	.07	-.745	.116	-.974	-.515	-6.40	.000*
	Female	3.23	.87	.09						
FSI (Protocol 3)	Male	2.24	.47	.05	-.565	.083	-.729	-.400	-6.78	.000*
	Female	2.81	.63	.06						

Significance level $p \leq 0.05$, *significant, C.I. = 95% Confidence Interval

TABLE (3): Results of receiver operator Characteristic curve (ROC) and area under the curve (AUC)

Test Result Variable(s)	Area under the curve	Std. Error	P value	Asymptotic 95% Confidence Interval	
				Lower Bound	Upper Bound
FSI (Protocol 1)	.320	.040	.000	.242	.398
FSI (Protocol 2)	.225	.035	.000	.156	.294
FSI (Protocol 3)	.224	.035	.000	.155	.293

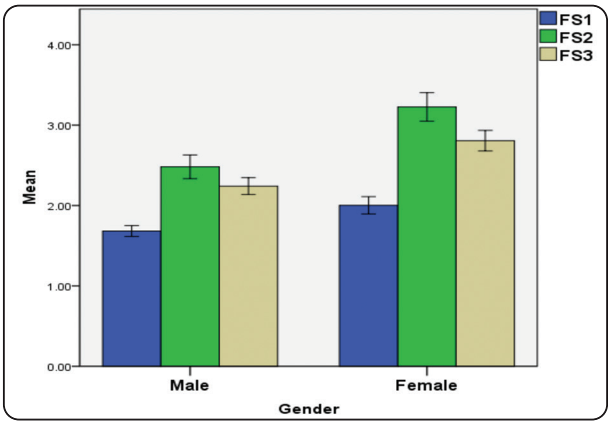

Fig. (5). Bar chart illustrating mean value of FSI different protocols in males and females

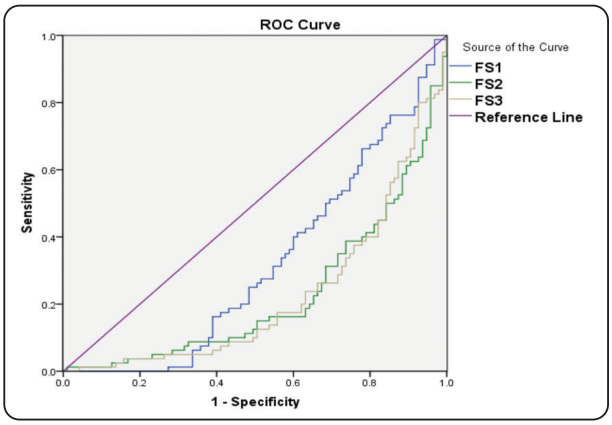

Fig. (6). Receiver operator characteristic curve (ROC) of different FSI protocols

TABLE (4): Sensitivity and specificity of different FSI protocols used for sex prediction at optimal cut-off values

Test Result Variable(s)	Female if Greater Than or Equal To	Sensitivity	Specificity
FSI (Protocol 1)	1.67	57.5%	24%
FSI (Protocol 2)	2.37	51%	14%
FSI (Protocol 3)	2.16	56%	15%

DISCUSSION

Precise determination of sex from the skeletal remnants of unidentified persons is a chief part of forensic research to approximate the biological profile of an individual.[4,22] The craniofacial structures have the advantage of being composed largely of hard tissues, which are comparatively enduring and indestructible. Therefore, the human skull has been widely studied for ante and post mortem identification both in anatomical and radiological assessments.[1,23]

Frontal sinus has very tough resilient walls and is preserved intact in human remains due to its internal bony structure and arched nature which protect it from damage and decomposition. Besides, its anatomical position in the glabellar region posterior to the thick frontal bone outer table enhances its strength.[24]

Radiology is a main tool for forensic science. It assists in the anatomical structures analysis for personal identification as well as estimation of biologic age and sex. Also, it is convenient for comparison of ante and post mortem records in forensic investigations.[22,25]

For craniofacial examination, cephalometric radiographs are preferred because they are more objective, standardized and reproducible. The frontal sinus is clearly visible on lateral cephalometric radiographs because of its unique air-filled cavity nature.[4,26] However, frontal sinus measurements on lateral cephalometric radiographs are liable to inherent magnification. Therefore, to overcome this problem, ratios are considered to be more dependable than individual absolute measurements.[13] That's the reason why the authors of the current study preferred to use the FSI obtained from measurements taken on digital lateral cephalometric radiographs.

To the best of our knowledge, this is the first forensic radiological study to evaluate three different FSI protocols measured on lateral cephalometric radiographs for sex estimation.

Considering both frontal sinus height and different frontal sinus width measurements which were obtained from lateral cephalometric images, an excellent inter-observer correlation (ranging from 0.974 to 0.997) was found except for the 3rd protocol width in males, which recorded acceptable correlation (0.788). This obviously demonstrates good consistency and reproducibility of the applied methodology through this study.

Regarding our results, it was found that FSI (Protocol 3) failed to act as a sex predictor. This was a nearly similar result to that stated by Luo et al., 2018[4] who used the same protocol to calculate the FSI and found that their approach did not lead to enough improvement of sex identification.

Although, Kiran et al., 2014[13] found that the FSI obtained using (Protocol 2) was significantly higher in females than males as the results of the current study and that of Kenawy et al, 2021[27], their study stated that FSI obtained with (Protocol 2) is a reliable sex differentiation adjunct tool as their calculated FSI was able to detect correct sex in 67.59% of their studied cases. This may be due to the different skeletal characteristics of Indian population from Egyptian one with genetic dissimilarities and different dietary habits resulting in different anatomical features.[28]

ElBeshlawy & Helaly, 2020[20] found that the FSI (Protocol 1) calculated from lateral cephalometric measurements was significantly higher in males than females above 18 years. Also, in their ROC analysis results, the FSI could only act as poor sex predictors (AUC: 0.66). These differences between their results and ours may be due to their small sample size (25 males and 25 females only).

Contradicting the current study results, Benghiac et al., 2015[1] using the FSI (Protocol 2) as sex discrimination tool found that FSI is somewhat predictive of gender where their discriminant function predicting gender was correct in 92% of females and only half of males. This may also be due to their small sample size and the different imaging modality used for frontal sinus analysis.

Some previous studies were performed to assess the frontal sinus in relation to sex in Egyptian population but none of them used any of the FSI measured protocols. In this context, Hamed et al, 2014 and Ibrahim et al, 2020[29,30] performed two different studies to evaluate the reliability of sex differentiation depending on various frontal sinus dimensions using CT and both found a statistically significant higher values for the maximum height, transverse and anteroposterior dimensions of both right and left sinuses in the male group than that in the female group. Furthermore, Sherif et al, 2017[31] evaluated the dimensions of different paranasal sinuses (including the frontal sinus) in sex estimation using multislice CT and revealed that the mean left and right sinuses depths and the left sinus height in males were significantly greater than in females. Additionally, another study by Motawei et al, 2016[32] concluded that inspite of the significant differences found between males and females in frontal sinus CBCT measurements, these measurements were exclusive and distinctive for every individual. The previous studies different frontal sinus assessment procedures could be the cause of the disagreement between their results and that of the current study.

CONCLUSION

Although our results did not lead to enough improvement of sex estimation based on different frontal sinus index protocols to permit its use in forensic applications, it highlights the major requirement for more research on this concern. Further sex discrimination studies using the FSI (Protocol 1) are recommended as this protocol had the highest sensitivity and specificity in the current study. As well, in the field of forensic medicine, additional research using more advanced imaging modlaities as CT and CBCT may offer additional information that may possibly improve sex estimation.

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