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Reliability of the frontal sinus index for sex determination using CBCT

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Abstract: This retrospective study aimed at assessing the reliability of morphometric measurements performed on the frontal sinus using the frontal sinus index (FSI) for sex determination on cranio-facial and sinuses CBCT scans. 77 CBCT explorations were performed by Planmeca 3D Mid (Planmeca, Helsinki, Finland) and Romexis 3.6 software (Planmeca, Helsinki, Finland) on adult individuals. The FSI was determined on mid-sagittal CBCT slices in all selected patients.

FSI is somewhat predictive of gender. When the discriminant function predicting gender based on log2FSI was applied to a validation dataset, 92% of females were correctly classified but only half of males were correctly classified. Adding width, height and age variables did not significantly increase the ability to predict gender. The predictive value of FSI for determining gender may need to be supplemented with other information to achieve a high level of accuracy.

Key Words: CBCT, sex determination, frontal sinus, forensic dentistry.

The frontal sinus is an aeric cavity located within the frontal bone. It develops during the fourth or fifth week of intrauterine life and continues to grow after birth until early adulthood by anterosuperior pneumatisation of the frontal recess into the bone [1]. It contains two chambers which are typically asymmetrical, due to the independent development of each sinus and which are separated by a bone septum [2].

The human skull has been extensively studied ante and post mortem for identification purposes both in anatomical and radiological assessments. Schuller was a pioneer in establishing the important role of the frontal sinus for sex determination [3]. A literature review on the forensic application of the frontal and maxillary sinuses focused on articles listed by PubMed and Scielo, published between 2003-2014, and selected articles that matched the search. Thirty articles were about human identification and sex determination using conventional X-rays and computed tomography [4]. A recent study shows that the frontal sinus volume calculated on CT scans can be a reliable method for sex determination [5]. New research underlines the role of cone-beam computed tomography (CBCT) in studying the frontal sinus for individual identification [6]. While various radiology and medical imaging studies about the frontal sinus implications in forensic dentistry were reported, the literature lacks sufficient information on sex determination using measurements performed on the frontal sinus from CBCT scans. Considering a previously proposed morphometric method, the frontal sinus index (FSI), which was acknowledged as being reliable for sex identification on lateral cephalograms [7], the present study aimed at assessing the reliability of the FSI for gender determination using CBCT explorations. Unlike previously mentioned studies performed on conventional CT [5] and on CBCT scans [6], this research focuses on linear, not volumetric measurements. The method is applicable for sex determination using linear

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measurements performed on mid-sagittal CBCT scans of the frontal sinus. Literature suggests that the frontal sinus assessment is universally accepted by anthropologists, criminal investigators, magistrates, physicians, including radiologists as a mean of sex identification, especially in edentulous individuals [8]. This fact is due to the unicity of the frontal sinus pattern, considering that it has been scientifically proven that even in monozygotic twins, the frontal sinus differs [8]. Thus, it has been stated that the frontal sinus assessment can even substitute fingerprints based on its individuality [9-11].

CBCT is an imaging device that uses a cone-shaped X-ray beam. The X-ray source and detector rotate around a field of interest of the patient named field of view (FOV). The received images are transferred into a computer that performs primary reconstructions which can be viewed as 2D multi-planar reformatted slices or in 3D [12]. The advancements in oral and maxillofacial radiology, together with the availability and affordability of CBCT devices, lead to an increase in scanning addressability in the field of dentistry, including forensics.

MATERIALS AND METHODS

This retrospective study was conducted on 77 CBCT scans from patients who had been referred to MedImagis, a private radiology and 3D imaging clinic in Iasi, Romania, during August 2013 - December 2014. The scans were selected from a database of 144 cranio-facial and sinuses CBCT explorations. The referrals were provided by dentists, ENT, DAS and OMFS specialists for diagnostic purposes and preoperative treatment planning of various surgical procedures.

All CBCT explorations were performed by Planmeca ProMax 3D Mid (Planmeca, Helsinki, Finland) on adult individuals using a standard exposure and patient positioning protocol and included the anatomical areas of interest: frontal sinus, Crista galli, anterior nasal spine (ANS) and posterior nasal spine (PNS). The obtained images were exported in a digital imaging communication in medicine (DICOM) file format (.dcm) and imported into a personal computer (Dell Latitude e6320, Dell Inc., TX, USA) using DICOM viewer Romexis 3.6 software (Planmeca, Helsinki, Finland). The scans were performed by a licensed radiology technician and read by two examiners: a graduate radiology and medical imaging student trained in CBCT (AGB) and an experienced senior radiologist (DH). In cases of disagreement, the final measurements were reached by consensus. After one month, all measurements were repeated.

The exclusion criteria were: minor patients due to incomplete development of the frontal sinus, excessive artifacts, congenital impairments, agenesis, pathology affecting the analyzed structures and history of surgery in the anatomical areas of interest.

The research was carried out in accordance with the principles described in the Declaration of Helsinki, including all amendments and revisions. The study protocol was approved by the Gr. T. Popa UMPh Ethics Committee (reference number: 13084, July 1st, 2015).

Previous studies using the frontal sinus index (FSI) (height/width ratio) as a maturity indicator [13] or tool for sex determination [7] were conducted on conventional 2D radiographs. The lateral cephalograms were analysed with the Nasion - Sella (NS) line horizontally. The highest (H) and the lowest point (L) of the frontal sinus were marked and the maximum height (MH) was obtained by uniting them. The maximum sinus width (MW) was established by connecting the anterior wall of the frontal sinus at its deepest portion to the maximum height line through a perpendicular line [7, 13]. The studies concluded that the FSI can be used as a reliable tool for sex determination [7] and that it is not reliable as a sole criterion for skeletal maturity prediction [13].

This research aimed at using the FSI, as previously defined, for sex determination on mid-sagittal slices generated from CBCT scans. To our knowledge, this is the first research regarding the reliability of the FSI measured on CBCT explorations. The images were obtained by sectioning in axial and sagittal view at the level of the palatal plane (the line drawn from ANS to PNS) and by sectioning at the level of Crista galli and PNS in coronal view. A value of 0.400 mm slice thickness was used (Fig. 1). All measuring parameters were drawn on the internal contour of the frontal sinus and measured in mm.

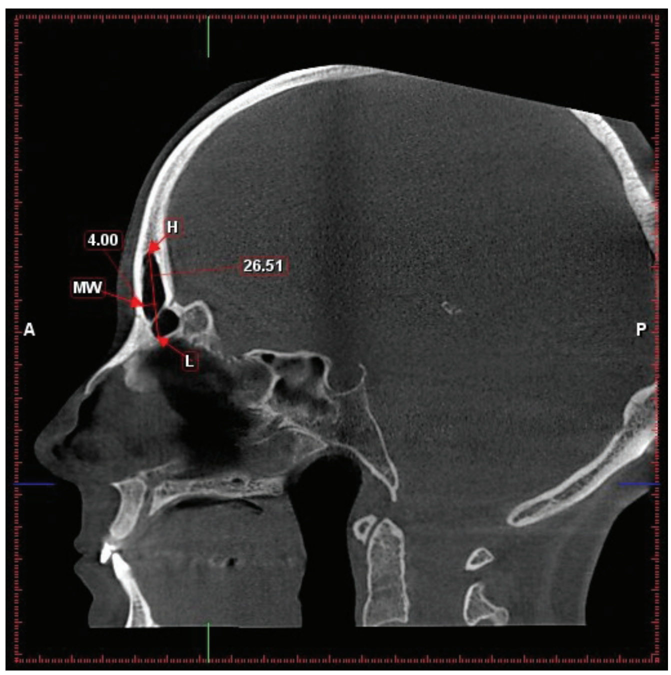

Figure 1. Frontal sinus measurements on mid-sagittal CBCT slice. H-highest point on the frontal sinus; L- lowest point on the frontal sinus; MW- maximum width of the frontal sinus.

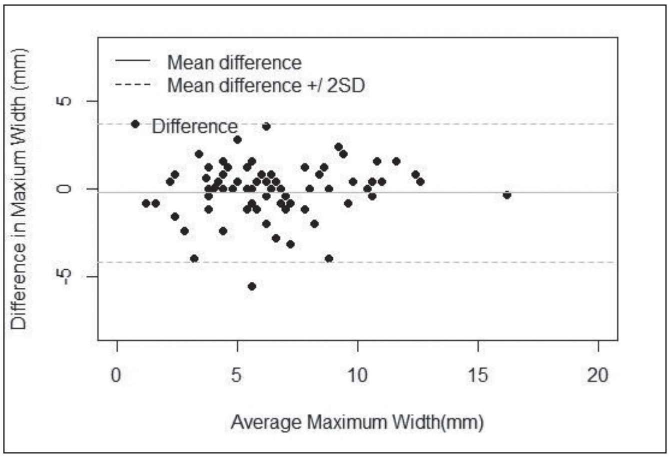

Figure 2. Bland-Altman agreement plot for maximum width.

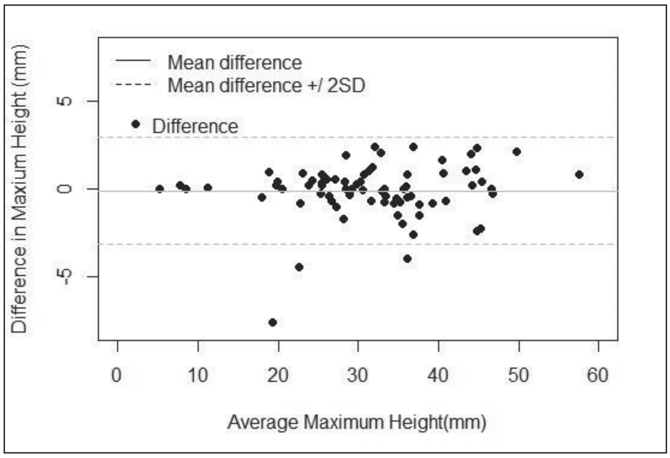

Figure 3. Bland-Altman agreement plot for maximum height.

In addition to the above mentioned measurements, demographic data including sex and age were recorded and correlated to the FSI.

Statistical analysis

Agreement between the first and second measures for maximum height and maximum width was assessed by computing the concordance correlation coefficient (CCC) [14] and Bland-Altman plots [15]. The replicate measures for maximum height and width were averaged and FSI was calculated as the maximum height/ maximum width and then log transformed. Differences in mean values by gender were assessed using t-test. The dataset was randomly divided into a training set and validation set. The training set was used to fit two predictive discriminant functions with gender as the dependent variable: the first model included $\log_2$FSI as a predictor and the second model included age, maximum height, maximum width and $\log_2$FSI as predictors. The estimated coefficients from the model were applied to the validation dataset and the percentage of correct predictions was calculated. All analyses were done with R software [16].

RESULTS

Seventy-seven scans were assessed. All scans were read in duplicate at a one month interval. Reliability as measured by the concordance correlation coefficient was 0.99 for the replicate maximum height measures and 0.79 for the maximum width measures, indicating that height was re-measured almost perfectly while width was re-measured with less precision but good agreement. Bland-Altman plots (Figs 2 and 3) confirmed that the replicate values were in high agreement with no detectable bias. The replicate measures were averaged within subject to give a single maximum height and maximum weight variable used in the subsequent analysis.

There were no missing data values. Forty-six (60%) of the subjects were female and thirty-one (40%) were male. Table 1 shows the summary measures for maximum height, maximum with and FSI ratio by gender and tests for mean differences.

Thirty-eight subjects (21 females and 17 males) were randomly allocated to a training dataset and 39 subjects (25 females and 14 males) allocated to a validation dataset.

Table 1. Mean (standard deviation) and test of mean differences by gender

	Overall	Female	Male	P-value for test of mean differences
Age (years)	40.6 (14.8)	43.3 (15.4)	36.7 (13.2)	0.05
Maximum Height(mm)	31.5 (9.8)	30.6 (9.5)	32.9 (10.2)	0.31
Maximum Width (mm)	6.5 (2.9)	5.2 (2.1)	8.3 (3.0)	< 0.0001
Log_2 FSI Ratio	2.34 (0.65)	2.57 (0.65)	2.00 (0.48)	<0.0001

Table 2. Actual *vs* predicted gender based on discriminant analysis with $\log_2$ FSI as the prediction variable

	N (%)	Predicted	
		Female	Male
Actual	Female	23 (92%)	2 (8%)
	Male	7 (50%)	7 (50%)

Table 3. Actual *vs* predicted gender based on discriminant analysis with $\log_2$ FSI, average maximum width, average maximum height and age as prediction variables

	N (%)	Predicted	
		Female	Male
Actual	Female	22 (88%)	3 (12%)
	Male	8 (57%)	6 (43%)

For the prediction of gender using log2FSI, the estimated coefficient was 1.84. Overall the accuracy of prediction on the training set with leave-one-out cross validation was 63% and the accuracy on the validation dataset was 77%. The confusion matrix is shown in Table 2. When the linear discriminant function was expanded to include the average maximum width, average maximum height, log2FSI and age, the overall accuracy on the training dataset was 0.66 and accuracy on the validation set was 0.72. Table 3 shows the confusion matrix.

CONCLUSION

FSI is somewhat predictive of gender. When the discriminant function predicting gender based on log2FSI was applied to a validation dataset, 92% of females were correctly classified but only half of males were correctly classified. Adding width, height and age variables did not significantly increase the ability to predict gender. The predictive value of FSI for determining gender may need to be supplemented with other information to achieve a high level of accuracy.

Conflict of interest. There are no competing interests to report.

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