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Radiographic Evaluation of Frontal Sinus Dimensions and Anatomic Variations

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Authors' contributions

This work was carried out in collaboration between all authors. All authors contributed extensively to the work presented in this paper. All authors read and approved the final manuscript.

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ABSTRACT

Aim: This study evaluated radiographic variations and measured dimensions of the non-pathologic frontal sinuses.
Study Design: Retrospective.
Place and Duration of Study: Orthodontics Department, Dental School, Shahid Beheshti University of Medical Sciences, 2003 to 2012.
Methodology: Subjects older than 12 years with no sinus pathology were included. Borders of the frontal sinus were traced. Line drawings were scanned, and sinus dimensions were calculated by computer software by two examiners. In addition, asymmetry and shape of superior margin of sinus were evaluated. Gender differences were analyzed by independent sample t-test and chi square with a 0.05 level of significance.
Results: A total of 66 subjects were included (40 female and 26 male). Height, width and area of the frontal sinus in the sagittal plane were 2.26 cm, 1.13 cm and 1.37 cm^2, respectively. The corresponding numbers in the frontal plane were 2.79 cm, 5.00 cm and 7.04 cm^2, respectively.

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Although all dimensions were larger in men than in women, it was not significant (P>0.05). Most of the cases had relatively symmetric frontal sinus.

Conclusion: Size and shape of the frontal sinus varies among individuals. Frontal sinus is relatively larger in men than women.

Keywords: Frontal sinus; anatomic variation; radiography; lateral cephalometry; posterior-anterior cephalometry.

1. INTRODUCTION

In 1871, Steiner described frontal sinus as the anterior ethmoid air cells which extended into frontal bone [1]. Since then, numerous studies have investigated anatomy of skull air cells for clinical or surgical purposes and skeletal growth prediction [1-4].

Pneumatization of frontal bone is directly influenced by interaction of the respiratory epithelium and activity of its adjacent osteoclasts [5]. Variations in the extent of the pneumatization individualize frontal sinus morphology and remarkable diversity in the shape, capacity and symmetry of the frontal sinus is found [6]. These variations lead to the forensic identification of the deceased comparing frontal sinus radiographs before and after death [7,8]. Pneumatization may also not occur in the frontal bone, which results in sinus aplasia [9]. Since the left and right sinuses are developed independently, asymmetrical sinuses may be found. Considering these variations and complicated radiologic interpretation of the frontal sinus due to the superimposition of skull anatomic structures [10], it is important to have the knowledge of the anatomy and dimensions of the frontal sinus for the treatment of chronic sinus pathologies and surgical interventions [11]. On the other hand, Rossouw et al. [2] revealed the relation between the lengths of maxilla, mandible, condyle and the lateral area of the frontal sinus. They have also suggested that the frontal sinus dimensions can be used to predict mandibular growth [2].

Despite the importance of the frontal sinus, limited investigations of the anatomy of these air cells has been lately performed. This aim of this study was to evaluate radiographic variations and measure dimensions of the non-pathologic frontal sinuses of Persian individuals.

2. MATERIALS AND METHODS

2.1 Study Population

A retrospective study of patients treated in the department of orthodontics of Dental School, Shahid Beheshti University of Medical Sciences, Tehran, Iran with in the years 2003 to 2012 was performed. The study design was approved by Research Institute of Dental Sciences, Shahid Beheshti University of Medical Sciences. Considering study design using documented data, no informed consent was taken. All the patients who met inclusion and exclusion criteria were included. Patients over 12 years of old, who had taken posterioanterior cephalometry (PA) and lateral cephalometry (LC) radiographic images with true scale were included in the study. All radiographs which were taken using the same machine and technique were included. Patients whose age or gender was not documented were excluded. Patients with a sinus infection or pathology (based on the radiology image), congenital syndrome involving craniofacial bones, including cleft palate, hemifacialmicrosomy or hypertrophy, history of orthognathic surgery or trauma to nasomaxillary complex were excluded.

LC and PA radiographs were taken in centric occlusion in a position where the patient's head was located at NHP, using a Cranex D X-ray unit (Sordex, Helsinki, Finland) at 66 to 70 kVp, 10 mA, and 14.2 s exposure.

2.2 Measuring Sinus

Measurement of sinus dimensions was performed on pre-treatment PA and LC radiographs. Sinus borders excluding crista galli were drawn on transparent tracing paper. In cases where there was no detectable level of the inferior sinus border, extension of the superior orbital rim was considered as the lower limit [12,13]. Inability to detect sinus on radiographs, was regarded as sinus aplasia. Accuracy of traced limits of sinus was controlled by an experienced orthodontist. Lines drawn on transparent paper and the papers were scanned by a digital scanner (Canon Inc., Tokyo, Japan). The most height, the most width and area of the frontal sinuses in two planes (sagittal and frontal) were measured by AutoCAD 2007 software (Autodesk Inc., San Rafael, CA) with the 2.5% error [14]. (Fig. 1) Measurements were performed by two examiners, and the values were averaged to calculate final measurements for each patient. To assess the inter-examiner reliability, intra-class correlation coefficient (ICC) was measured.

Frontal sinus anatomic variations, including relative size, symmetry, and also form of the superior margin were assessed on a qualitative basis on PA radiographs (12). Sinus area was categorized into four groups (0-6 cm^2: small, 6-12 cm^2: middle, 12-18 cm^2: large and >18 cm^2: very large) (12). Frontal sinus radiographic appearance was categorized based on the upper edge of the sinus (12).Categories used were: 0, absence of scalloped shape; 1, smooth scallops; 2, scalloped with 2 arcades; 3, scalloped with 3 arcades; 4, scalloped with four arcades and 5, scalloped with over five arcades Midsagittal plane was drawn from the anterior nasal spine to nasion point. Area of the left and right frontal sinus was calculated based on the extension of the midsagittal plane. To assess the symmetry of right and left sinus, asymmetry index (12) was used according to the sinus area. The index formula is as follows:

$$\text{Asymmetry Index} = A1/A2 \times 100$$

The smaller sinus area is assigned to A1, and the larger sinus area is assigned to A2 in the mentioned formula. The superior margin of the frontal sinus was assessed based on the presence of separating bone septa.

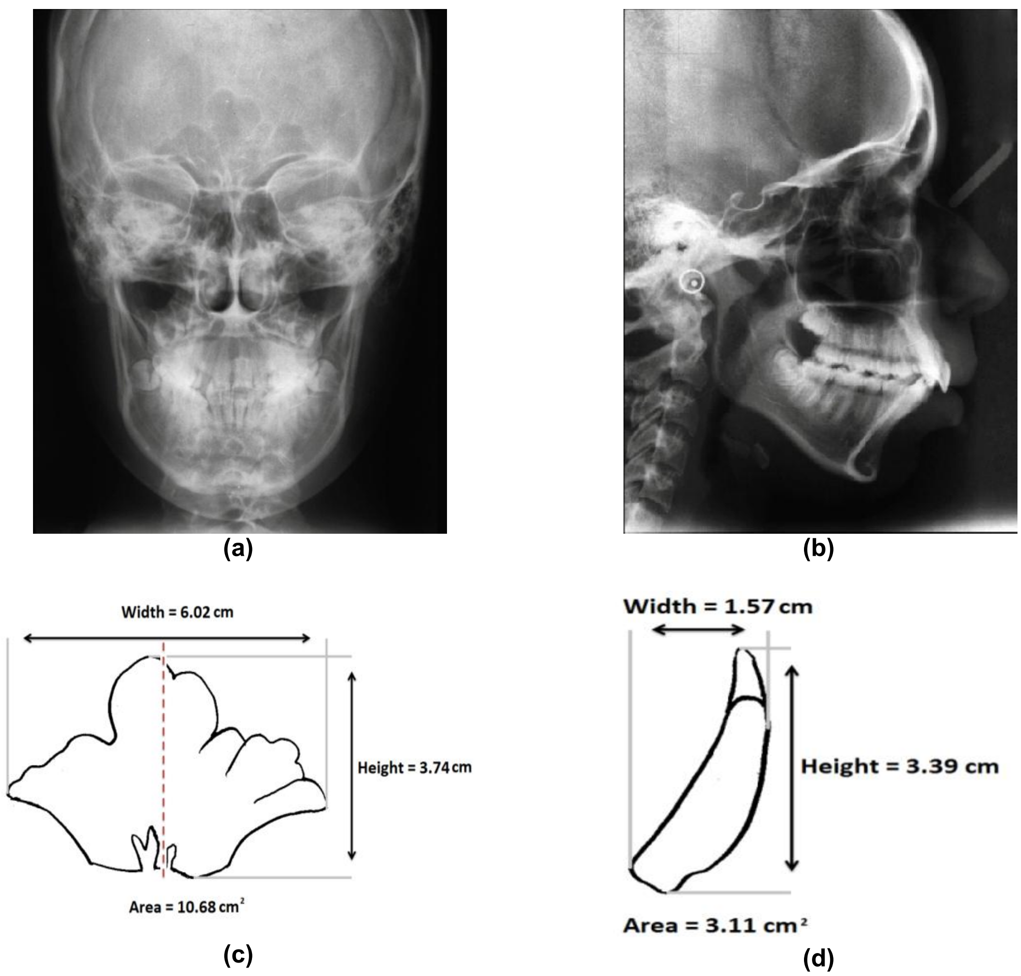

Fig. 1. A sample measurement of frontal sinus dimensions; a) Posterio anterior cephalogram b) Lateral cephalogram c) frontal sinus trace and measurements on frontal plane (dots show midsagittal plane) d) Frontal sinus trace and measurements on sagittal plane

2.3 Statistical Analysis

Data was presented based on descriptive statistics (mean±SD). The normal distribution of measurements was assessed by Kolmogorov-Smirnov test. Student's t-test for independent samples was used to compare gender differences in sinus dimensions and differences in age groups were analyzed by One-Way ANOVA. The relationships between measurements were assessed by the Pearson Correlation Coefficient. The Chi-square test was used to compare the anatomical variation between male and female patients. Statistical analysis was performed by SPSS v.19 software and with a significance level of 0.05.

3. RESULTS

3.1 Dimensions of Frontal Sinus

A total of 66 subjects were enrolled, of which 40 were females and 26 were males. The average age of samples was 19.28±4.46 years (13 to 31 years). In two female patients (3%) bilateral aplasia was found and three cases (4.5%) (two males and one female) had unilateral sinus aplasia. ICC for inter-examiner reliability was 0.81, which is considered as excellent correlation. Average dimensions of the frontal sinus are given in Table 1. Kolmogorov-Smirnov showed normal distribution of measurements ($P>0.05$). The size of the frontal sinus has many variations. The average area of the left and right frontal sinus was 3.55±1.76 and 3.49±1.96 cm^2, respectively, which was not significantly different (p value = 0.534).

The mean of dimensions in both sagittal and frontal plans were greater in males compared to females; however, such difference was not statistically significant except the sinus width in frontal plane (p value = 0.17) (Table 2).

ANOVA test results did not show significant differences between age groups (4 years). Additionally, there was no difference between sinus dimensions in patients less and more than 16 years old (puberty).

Table 1. Average dimensions of the frontal sinus in sagittal and frontal plane (width and height in cm and area in cm^2 Sample size: 66)

	Minimum	Maximum	Mean	Std. deviation	
Lateral cephalometry	Width	.39	2.00	1.1295	.38919
	Height	1.18	3.36	2.2643	.57888
	Area	.3168	3.8837	1.368990	.7815756
Posterioanterior cephalometry	Width	.43	7.88	4.9972	1.42836
	Height	.65	5.96	2.7866	.77011
	Area	.1470	19.8910	7.039053	3.5953790

Table 2. Gender differences in dimensions of the frontal sinus (width and height in cm and area in cm^2 Sample size: 66)

			Mean	Std. deviation	Sig. (2-tailed)	Mean difference
Lateral cephalometry	Area	Male	1.397543	.5203720	.857	.0448680
		Female	1.352675	.9064521		
	Width	Male	1.1944	.36622	.410	.10187
		Female	1.0925	.40349		
	Height	Male	2.3706	.52975	.363	.16705
		Female	2.2036	.60601		
Posterioanterior cephalometry	Width*	Male	5.5239	1.38472	.017	.86418
		Female	4.6597	1.36822		
	Height	Male	2.9700	.91089	.128	.30106
		Female	2.6690	.65029		
	Area	Male	8.113409	3.9619475	.055	1.7630458
		Female	6.350363	3.2048611		

** Significant (p value<0.05)*

Significant association between changes in width, height and area of the frontal sinus was found (Table 3). However, the correlation between the dimensions of each plane was better (r in the sagittal plane between 0.631 and 0.883 and r in the frontal plane between 0.728 and 0.892) compared to correlation between the two planes (r between 0.560 and 0.367).

3.2 Frontal Sinus Anatomic Variations

Frontal sinus was divided into four categories based on sinus area in PA radiographs (Table 4). Although the frontal sinus area in females was mostly categorized in the small group (55%), no significant differences in relative frequency of each category between males and females were found (Chi-Square value Square value = 4.53 and P value = 0.209).

Frontal sinus in all samples was asymmetric. The area of the left sinus was larger than the right one (P = 0.109). In most cases relative symmetry (more than 80% symmetry) of the frontal sinus area was observed in both male and female patients (Table 5). While slight asymmetry (60-80% symmetry) and extreme asymmetry (symmetry less than 20%) were more frequently observed in females than in males, the difference was not statistically significant (Chi-Square value Square value = 3.32 and P value = 0.345).

Superior border of the frontal sinus was mostly scalloped (Table 6). No significant differences were observed between males and females (Chi-Square value Square value = 5.95 and P value = 0.311).

4. DISCUSSION

Frontal sinus is known as one of the anatomical structures that are found only in humans and some apes in Africa [15]. Previous studies have reported variations in the shape and size of the frontal sinus in relation with sex, age and dimensions of the skull [6]. In addition, genetic factors and weather conditions influence sinus dimensions in each population [16]. This study was aimed at understanding and measuring this anatomical structure in an Iranian population. The results showed that the frontal sinuses vary greatly in terms of size and appearance. Height, width and area of the frontal sinus in the sagittal plane were 2.26 cm, 1.13 cm and 1.37 cm^2, respectively. The corresponding numbers in the frontal plane were 2.79 cm, 5.00 cm and 7.04 cm^2, respectively.

Table 3. The correlation between the dimensions of the frontal sinus in sagittal and frontal planes

		Width (lateral view)	Height (lateral view)	Area (lateral view)	Width (frontal view)	Height (frontal view)	Area (frontal view)
Width (lateral view)	Pearson Correlation	1	.631**	.883**	.455**	.455**	.391**
	Sig. (2-tailed)		.000	.000	.002	.002	.009
Height (lateral view)	Pearson Correlation	.631**	1	.767**	.527**	.560**	.546**
	Sig. (2-tailed)	.000		.000	.000	.000	.000
Area (lateral view)	Pearson Correlation	.883**	.767**	1	.367*	.445**	.380*
	Sig. (2-tailed)	.000	.000		.014	.002	.011
Width (frontal view)	Pearson Correlation	.455**	.527**	.367*	1	.728**	.846**
	Sig. (2-tailed)	.002	.000	.014		.000	.000
Height (frontal view)	Pearson Correlation	.455**	.560**	.445**	.728**	1	.892**
	Sig. (2-tailed)	.002	.000	.002	.000		.000
Area (frontal view)	Pearson Correlation	.391**	.546**	.380*	.846**	.892**	1
	Sig. (2-tailed)	.009	.000	.011	.000	.000	

***. Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed)*

Table 4. Distribution of samples based on the area of the frontal sinus

Class number	Degree	Range (cm^2)	Male		Female	
			Count	%	Count	%
1	Small	0-6	8	32.0%	21	55.3%
2	Middle	6-12	14	56.0%	14	36.8%
3	Large	12-18	2	8.0%	3	7.9%
4	Very large	>18	1	4.0%	0	.0%

Table 5. Distribution of samples based on the symmetry of the left and right frontal sinus

Class number	Degree of bilateral asymmetry	Range of asymmetry index	Male		Female	
			Count	%	Count	%
1	Symmetry and almost symmetry	100-80	17	68.0%	21	53.8%
2	Slight asymmetry	80-60	7	28.0%	13	33.3%
3	Moderate asymmetry	60-40	1	4.0%	1	2.6%
4	Strong asymmetry	40-20	0	.0%	0	.0%
5	Extreme asymmetry	<20	0	.0%	4	10.3%

Table 6. Distribution of samples based on the superior margin of the frontal sinus

Class number	Outline of upper border	Male				Female			
		Right		Left		Right		Left	
		Count	%	Count	%	Count	%	Count	%
0	Absence of scallop	4	15.4%	5	19.2%	9	22.5%	14	35.0%
1	Smooth scallops	6	23.1%	5	19.2%	12	30.0%	11	27.5%
2	Scalloped with 2 arcades	7	26.9%	10	38.5%	12	30.0%	11	27.5%
3	Scalloped with 3 arcades	6	23.1%	5	19.2%	5	12.5%	3	7.5%
4	Scalloped with 4 arcades	3	11.5%	1	3.8%	1	2.5%	0	.0%
5	Scalloped with above 5 arcades	0	.0%	0	.0%	1	2.5%	1	2.5%

Previous studies have shown that all aspects of the frontal sinus are greater in men than women [17-20]. In study of Brown et al. [17] the height of the frontal sinus in the frontal plane was 3.26 cm in males and 2.66 cm in females and in the study by Harris et al. [18] it was 3.01 cm in males and 2.60 cm in females. The width of the frontal sinus in the frontal plane has been reported 5.83 cm in males and 4.69 cm in females [19]. In the current study, the height of the frontal sinus was 2.97 cm in males and 2.67 cm in females, and the width of the frontal sinus was 5.52 cm in males and 4.67 cm in females. Although the relatively larger size of the sinuses in men, like the current study was not always statistically significant [12,21], considering the results of previous studies, one can conclude that the size of the frontal sinus is slightly gender dependent.

Pobornikova, assessing frontal sinus radiography of one t o13 years old children, reported that sinus grows horizontally in girls while in boys, vertical growth is more dominant [22]. He also revealed that the left frontal sinus is larger than the right one. Similarly, Gulisano et al. [23] observed that left frontal sinus is larger than the right one. In the current study area, the left frontal sinus was larger than the right, although this difference was not significant.

Independent pneumatization of right and left frontal sinus results in the asymmetrical appearance. In this study, all samples had asymmetric frontal sinuses. These asymmetries were divided into five categories [12]. More than half of the subjects had 80-100% symmetry in the sinuses while less than 60% symmetry was found in a few cases (mostly females). In study of Yoshino et al. [12] in Japan, 40% samples of both sexes had 40-60% symmetry while in a study in Austria 40% of men had 60-80% symmetry, and about 40% of women had 80-

100% symmetry [24]. It seems that symmetry of the left and right frontal sinus is affected by racial features. The evaluation of frontal sinus appearance in this study demonstrated that arcade appearance was more frequently observed in males, while in females only smooth arches or no scalloped appearance could be detected. Schuller also reported that in females, the scalloped shape with smooth arcades is dominant [21].

Sinus aplasia was reported in 5% [20,21], 4.8% [23] and 3.8% [9] of adult cases. Similar to the present study, sinus aplasia has been observed more frequently in women in the cited studies. Frontal sinus aplasia was observed in 3% of cases herein. However, in Eskimos population sinus aplasia has been reported relatively more (25-36%); probably due to adaptation to the cold weather of polar zones [13].

Previous studies have demonstrated that frontal sinus dimensions face little physiologic changes after age 12 [20,21,24] and small alterations occur following sinus pneumatization. Therefore, in the current study patients older than 12 years were included so that sinus dimensions in adults would be analyzed. However, in certain diseases such as sinusitis and in the elderly, frontal sinus may enlarge due to bone loss [25,26]. The oldest sample in this study was 31 years old and sinus dimensions showed no significant association with age.

One of the limitations of the current study is small sample size. Cephalometric radiographs are mostly indicated in individuals with craniofacial anomalies or defects. Due to relatively small sample size, the results could not be generalized. As mentioned in study design, all available patients meeting inclusion / exclusion criteria were included. Due to small sample size, the study has a wide margin of error. Another limitation is 2-dimensional measurement of a complex 3-dimensional anatomic structure which is the inherent limitation of conventional radiographies.

4.1 Clinical Significance

Rossouw and colleagues [2] showed a fair correlation between frontal sinus area in the sagittal plane and increased anteroposterior growth of the mandible. As the sinus area increases, mandibular growth is more likely to happen [2]. Therefore, the size of the frontal sinus can be used as a predictor factor of mandibular growth. This factor can also be considered as an index for initial workup and treatment planning of patients with prognathic mandibles to evaluate the patients' needs for further orthognathic surgeries or orthodontic tooth movements.

Extension of the frontal sinus in the anteroposterior dimensions could happen either laterally (and thus prominence of superciliary arch) or medially in association with the dura. Extension of sinus towards dura causes thinning of the bone wall and increases the probability of intracranial involvement of sinus infections [1]. Frontal sinuses can also extend mediolaterally. Due to the close relation of sinus with orbits, there is the possibility of eye injury in these cases during sinus surgery increases [27].

5. CONCLUSION

Frontal sinus is an anatomic structure with diversity in size and shape, which was found in most cases (97%) of the study population. There was a significant correlation between various dimensions of this structure, and it is relatively larger in size in males than females. In addition, the morphology of the frontal sinus is different between females and males.

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CONSENT

All authors declare that written informed consent was obtained from the patient for publication of his / her radiographs.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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