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Volumetric Evaluation of Maxillary and Frontal Sinuses in 9–14 year old children — A Cone-Beam Computed Tomography Pilot Study

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Abstract

Context: Literature sums up numerous advantages of volumetric evaluation of maxillary and frontal sinuses in the field of pathology and forensic sciences. However, studies involving paediatric age groups are scarce. **Aims and Objectives:** To evaluate the volumes of maxillary and frontal sinuses in children aged 9–14 years of age and establish a correlation, if any, between the volumes and the age and sex of the children. **Settings and Design:** A retrospective study. **Materials and Methods:** Volumetric measurements of the maxillary and frontal sinuses were conducted on CBCT scans of 30 children aged 9-14 years, divided into three groups, those aged 9–10 years in group A, 11-12 years in group B, and 13-14 years in group C. **Statistical Analysis Used:** One way ANOVA test to compare the sinus volumes within the groups and unpaired t-test to compare the difference in the volumes in males and females as well as between right and left maxillary sinuses were used. **Results:** The mean values of the volumes of the right and left maxillary, total maxillary, and frontal sinuses in Group A were 8.4940±1.1966 cm^3, 8.3774±1.2047 cm^3, 16.8714±2.1212 cm^3, and 2.1903±0.8870 cm^3; in Group B were 8.7553±0.9067 cm^3, 8.3937±1.1461 cm^3, 17.1490±1.5732 cm^3, and 3.0469±1.5907 cm^3; and in Group C were 11.9895±2.230 cm^3, 12.6164±1.6797 cm^3, 24.6059±4.38536 cm^3, and 7.6546±1.7763 cm^3, respectively. The difference in the values among all three age groups was statistically significant ($p < 0.001$). However, there was no significant difference in the values between males and females or between the right and left maxillary sinuses. **Conclusion:** The study provides volumetric data of maxillary and frontal sinuses in paediatric age groups and proposes a correlation of the volumes with the age of the children.

Keywords: Frontal Sinus Volume, Maxillary Sinus Volume, Paediatric Age Group

Introduction

Comprehensive knowledge with appropriate visualization of the paranasal sinuses is crucial for performing successful head and neck, skull-base, and maxillofacial surgeries[1,2]. Moreover, the paranasal sinuses exhibit a significant inter-individual variation attributable to complex anatomy. This renders them bright areas for exploitation in forensics by aiding in the age and sex determination of individuals. Literature mentions a great deal of data supporting the applicability of maxillary and frontal sinus volumes in the age and sex determination of individuals[3–6].

The extent of pneumatisation of the maxillary sinus varies from person to person, and its volume is influenced by age[7]. It being the first paranasal sinus to form, the development starts as early as in the 17th week of the prenatal period; however, it is only after birth that the majority of growth occurs[8]. Maxillary sinuses remain intact even in explosions, warfare, and other mass disasters such as aircraft crashes, even when the skull and

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other bones may become badly disfigured, rendering an advantage on the forensic front[3].

Likewise, morphometric dimensions of the frontal sinus have been tested as reliable indicators for forensic purposes. The frontal sinus, generally, is the last sinus to develop, and the formation begins around the fourth or fifth month of intrauterine life, with pneumatisation reaching the frontal bone by around the second year of life[9]. The size becomes more conspicuous by the second or third year of life, and further expansion into the vertical portion of the frontal bone begins around the fifth year, with most children over the age of six demonstrating vertical projection radiographically. Enlargement of the sinuses occurs during puberty with a small additional increase in height several years after this growth spurt in some individuals, and frontal sinus growth is generally completed by the 20th year of life. However, the morphology remains practically unchanged during one's entire adult life.

Moreover, the low frequency of maxillary and frontal sinus hypoplasia and/or aplasia dictates a highly significant morphological characteristic for reliable identification of an individual based on the comparison of antemortem and post-mortem radiographs[10,11].

Various methods have been prescribed in literature for deriving frontal and maxillary sinus volumes, including Computed Tomography (CT) and Magnetic Resonance Imaging (MRI)[12–15]. However, all the mentioned diagnostic aids have been reported to have disadvantages namely invasiveness, lack of availability, expensiveness, and high radiation exposure. Recently Cone-Beam Computed Tomography (CBCT) has been used as a method to evaluate maxillary and frontal sinus volumes[14–16].

Although there are extensive studies producing data on the maxillary and frontal sinus volumes, those involving paediatric age groups are scarce. Thus, the aim of the present study was to evaluate the volumetric measurements of the maxillary and frontal sinuses in 9-14-year-old children using CBCT, which is considered to be the most effective tool for evaluation, thus raising the platform of the volumetric data of these sinuses in the lesser studied age-group of population and aiding in further extensive studies.

Methods

This retrospective study was conducted with the clinical and CBCT records of 30 children (18 males and 12 females) in the age range of 9-14 years. The subjects were divided into three groups: Group A, comprising children in the age range of 9-10 years; Group B, comprising those in the age range of 11-12 years; and Group C, comprising those in the age range of 13-14 years, with 10 children in each group. Children with a history of mid-facial trauma or cleft lip or palate were excluded from the study. Likewise, children with a history of orthodontic treatment or orthognathic surgery, trauma or any surgery of the skull, any systemic disturbance, or hereditary facial asymmetry were excluded from the study. A thorough clinical examination of the children was performed and written informed consent was obtained from the parent/guardian of each of them. The CBCT scans were performed with Planmeca ProMax 3D Mid (Planmeca, Helsinki, Finland), and the acquisition protocol was tailored to include the anatomical areas of interest corresponding to the maxillary and frontal sinuses. The obtained images were exported in DICOM (.dcm) format into a laptop and analyzed using Romexis 4.4.0. Software (Planmeca, Helsinki, Finland).

Maxillary (right and left) and frontal sinuses were marked using an ellipsoid tool in the coronal section, and then, using the air cavity tool, the volume of each of the sinuses was calculated (Figures 1 and 2).

The study was approved by the institutional ethical committee and was conducted in accordance with the Declaration of Helsinki (2000).

Statistical Analysis

For statistical purposes, we documented the age and sex of each patient. All statistical analyses were performed using the SPSS software, version 22 (SPSS Inc., Chicago, IL, USA). One-way ANOVA test was used to compare the groups, and an unpaired t-test was used to compare the difference in the sinus volumes between males and females and between the right and left maxillary sinuses.

Results

The study comprised 18 males and 12 females (Table 1).

The mean values of volumes of the right and left maxillary sinus, total maxillary sinus, and frontal sinus in Group A were 8.4940±1.1966 cm^3, 8.3774±1.2047 cm^3, 16.8714±2.1212 cm^3, and 2.1903±0.8870 cm^3, respectively; in Group B were 8.7553±0.9067 cm^3, 8.3937±1.1461 cm^3, 17.1490±1.5732 cm^3, and 3.0469±1.5907 cm^3, respectively;

and in Group C were 11.9895±2.230 cm^3, 12.6164±1.6797 cm^3, 24.6059±4.38536 cm^3, and 7.6546±1.7763 cm^3, respectively. The difference in the values among all three age groups was statistically significant ($p < 0.001$) (Table 2).

The mean value of total maxillary sinus volume in males was 19.2679±4.4043 cm^3 and in females was 19.9533±4.5182 cm^3, and the difference was statistically insignificant (p=0.68). Likewise, the mean value of frontal sinus volume in males was 3.8889±2.3688 cm^3 and in females was 4.9098±3.4126 cm^3, the difference being statistically insignificant (p=0.34) (Table 3).

The mean value of the right maxillary sinus volume was 9.7463±2.2049 cm^3 and of the left maxillary sinus volume was 9.7958±2.4184 cm^3, and the difference was statistically insignificant (p=0.934) (Table 4).

Table 1. Sex-wise distribution of the children included in the study

	Frequency	Percentage
Male	18	60.0
Female	12	40.0
Total	**30**	**100.0**

Table 2. Comparison of the maxillary and frontal sinus volumes among the different age groups

	Group	N	Mean (cm^3)	Std. Deviation (cm^3)	ANOVA	Post-hoc
Right Maxillary Sinus	A (9–10 years)	10	8.4940	1.19668	<0.001	(A=B)<C
	B (11–12 years)	10	8.7553	0.90679		
	C (13–14 years)	10	11.9895	2.23309		
	Total	30	9.7463	2.20495		
Left Maxillary Sinus	A (9–10 years)	10	8.3774	1.20479	<0.001	(A=B)<C
	B (11–12 years)	10	8.3937	1.14615		
	C (13–14 years)	10	12.6164	1.67970		
	Total	30	9.7958	2.41842		
Total Maxillary Sinus	A (9–10 years)	10	16.8714	2.12123	<0.001	(A=B)<C
	B (11–12 years)	10	17.1490	1.57320		
	C (13–14 years)	10	24.6059	3.49481		
	Total	30	19.5421	4.38536		
Frontal Sinus	A (9–10 years)	10	2.1903	0.88700	<0.001	(A=B)<C
	B (11–12 years)	10	3.0469	1.59074		
	C (13–14 years)	10	7.6546	1.77637		
	Total	30	4.2973	2.82232		

Table 3. Comparison of the mean volumes of maxillary and frontal sinuses among males and females

	Sex	N	Mean (cm^3)	Std. Deviation (cm^3)	P value
Total Maxillary Sinus	Male	18	19.2679	4.40431	0.68
	Female	12	19.9533	4.51828	
Frontal Sinus	Male	18	3.8889	2.36880	0.34
	Female	12	4.9098	3.41261	

Table 4. Comparison of the mean values of right and left maxillary sinus volumes

	N	Mean (cm^3)	Std. Deviation (cm^3)	P value
Right Maxillary Sinus	30	9.7463	2.2049	0.934
Left Maxillary Sinus	30	9.7958	2.4184	

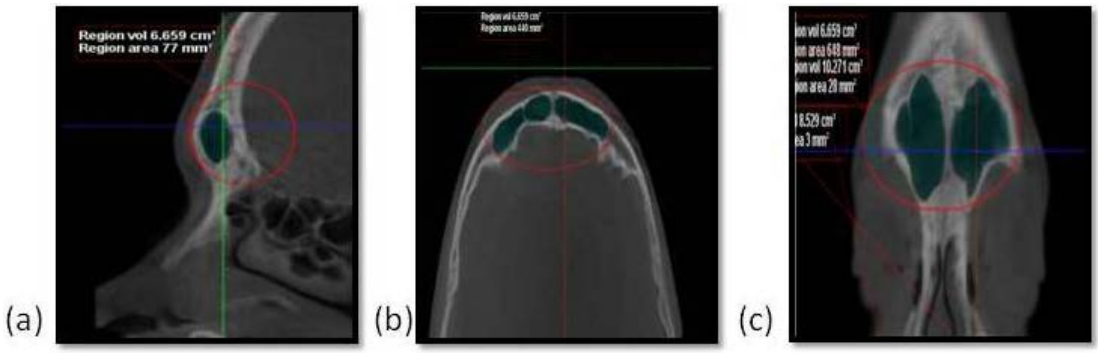

Figure 1. Volumetric measurement of the maxillary sinus in (a) sagittal, (b) coronal, and (c) axial planes in a 12-year-old male child. Note the sinus mucosa with normal thickening, lining the walls of the cavity.

Figure 2. Volumetric measurement of the frontal sinus in (a) sagittal, (b) coronal, and (c) axial planes in a 12-year-old male child. Note the sinus mucosa with normal thickening, lining the walls of the cavity.

Discussion

Evaluation of the volume of the paranasal sinuses is not only simple but also a significant parameter for the exploitation of these sinuses in pathological and forensic sciences. Although such volumetric studies have been performed in all age groups, those including the paediatric age groups are relatively scarce[12,18–20]. Thus, we included children in the age group of 9-14 years in our study, to present and expand data in paediatric age groups.

Measurement of sinus volumes has been performed using various methods in the past, including injections of various materials into the sinuses, stereology, use of the ellipsoid formula, etc. Recently, programs allowing segmentation and modelling based on semi-automatic processing of CT and MRI have been extensively used for volume measurements. These methods are compatible with three-dimensional imaging techniques and enable morphometric measurements. The technique of CT of the paranasal sinuses has already become a cornerstone in the evaluation and management of patients with sinus disease as well as in the age and sex determination of individuals in forensic sciences[17]. Moreover, it has expanded our vision into the anatomical features and variations of the sinus system, allowing a better assessment of pneumatisation of the paranasal sinuses[12]. During the last decade, CBCT, first reported in the literature by Mozzo *et al.*,[21] has been proposed for maxillofacial imaging and has gained recognition worldwide. A CBCT scan differs from CT in the type of image acquisition process that it employs. Rather than capturing an image as separate slices, as in CT, CBCT produces a cone-shaped X-ray beam making it possible to capture the image in a single shot. The resultant volume can be reformatted to provide multiple reconstructed image perspectives such as sagittal, coronal, and axial views. Furthermore, CBCT offers an advantage of a lower dose of radiation than CT, especially in a limited field of view, and particularly, while evaluating maxillary sinuses[22]. Thus, we employed the use of CBCT for the volumetric evaluation of maxillary and frontal sinuses in our study.

The development of the paranasal sinuses begins prenatally and continues lifelong. Between one and seven years of age, paranasal sinuses continue their expansion in all directions, attributable to the development of the nasal cavity and expansion of other facial structures. Pneumatisation of the paranasal sinuses is nearly completed between 12 and 14 years of age, reaching adult proportions. In our study, we found the mean total maxillary volume in children aged 9-10 years as 16.8714±2.1212 cm^3, in children aged 11-12 years as 17.1490±1.5732 cm^3, and in children aged 13-14 years as 24.6059±4.38536 cm^3, and the difference in the values was statistically significant. This was partly in accordance with the study conducted by Bhushan *et al.*,[23] who proposed that the height of the maxillary sinus had steady growth from birth to at least the age of 18 years, while the width and depth increased up to 12 years of age. They concluded that the values of maxillary sinus volume had significant differences before the age of 12 years, with no statistically significant difference beyond 12 years of age. However, the partial disagreement in both studies can be attributed to the fact that we included children only up to the age of 14 years, unlike the inclusion of children up to 18 years of age in the other study mentioned.

The mean values of right and left maxillary sinus volumes were 9.7463±2.2049 cm^3 and 9.7958±2.4184 cm^3 respectively and the difference was found to be statistically insignificant. This was in accordance with the study conducted by Bhushan *et al.*,[23] who compared the values in patients less than 18 years of age.

The mean value of frontal sinus volume in our study was 2.1903±0.8870 cm^3 in children aged 9-10 years, 3.0469±1.5907 cm^3 in children aged 11-12 years, and 7.6546±1.7763 cm^3 in children aged 13-14 years of age. Park H *et al.*,[12] in their study proposed that the frontal sinuses begin to pneumatise from two years of age, exhibiting a faster growth pattern between six and 19 years of age. The mean volume that they found after the full growth of the frontal sinuses was 3.46±0.78 cm^3. Sonam A *et al.*,[13] suggested that the area of frontal sinuses increased with age, except in males who were 45 years of age and above. However, Michel J *et al.*,[30] in their study on individuals above 16 years of age stated that there was no correlation between age and frontal sinus volume.

In our study, the mean value of total maxillary sinus volume in males was 19.2679±4.4043 cm^3 and in females was 19.9533±4.5182 cm^3, and the difference was statistically insignificant (p=0.68). This was contrary to the studies mentioned in the literature, exhibiting a significant difference in the values of the maxillary sinus volumes between males and females, except in those under six years of age[24–27]. However, the contradiction can at present not be considered definite enough, as

most of the studies included individuals above the age of 18 years[24–26], with only a single study including the paediatric age groups[27].

Likewise, the mean value of frontal sinus volume in our study was 3.8889±2.3688 cm^3 in males and 4.9098±3.4126 cm^3 in females, and the difference was statistically insignificant (p=0.34). However, Michel J *et al.*[30] in their study found the frontal sinus volumes to be significantly higher in males than in females. The contradiction can again be attributable to the age group of individuals included in the study, with the included individuals in their study being above 16 years of age. Although any other study correlating frontal sinus volumes and sex was not found, few studies trying to correlate other morphometric parameters of frontal sinus with sex have been found, with each of them exhibiting contradictory results. For instance, Mathur *et al.*,[31] in their study on individuals with a mean age of 21 years proposed significant differences in the width and height of frontal sinus among males and females. On the contrary, Kaur N *et al.*,[32] in their study on individuals aged 20 to 36 years, found no significant difference in the frontal sinus areas between both genders. In addition, Belaldavar *et al.*,[33] in their study on individuals aged 25 to 30 years stated that the frontal sinus provides an average accuracy in sex determination among the Indian population and attributed the cause to its greater variation in morphology. Thus, no consensus can be reached on the correlation of frontal sinus volume with gender due to the scarcity of studies.

The limitations of our study include the small size of the study sample; to arrive at conclusive findings, studies with larger sample sizes are required to be conducted. Moreover, data from adult age groups were not collected for the purpose of better comparison of the values among the same space of population. However, our study is entirely concentrated on paediatric age groups and is being conducted on individuals with no sinus pathologies, which holds an important position in the field of research as a weighty reference in the arena of maxillary and frontal sinus volume analysis for pathological or forensic studies.

Conclusion

To conclude, our study outlines the normal volumes of maxillary and frontal sinuses in children aged 9-14 years. These values may aid clinicians and researchers in better delineating the cases of sinus pathologies and determining the progression of pathological processes in an appropriate clinical context. The study also proposes a significant difference in the values of sinus volumes in different age groups- a proposal that can be exploited in future for age determination of individuals with the help of volumetric evaluation of these sinuses.

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