

Anatomical Variations of the Frontal Sinuses in Sudanese Children

Motaz A. NuggedAlla^{1*}, Amir Mohamed Ali²

¹Department of Anatomy, University of Al-Butana, Rufaa, Sudan

²Department of Anatomy, University of Gezira, Wad Madani, Sudan

*Correspondence to: Motaz A. NuggedAlla, Department of Anatomy, University of Al-Butana, Rufaa, Sudan, E-mail: motaz82sd@yahoo.com

Received: August 22, 2026; Manuscript No: JCTM-26-6260; Editor Assigned: August 29, 2026; PreQc No: JCTM-26-6260 (PQ); Reviewed: September 03, 2026; Revised: September 04, 2026; Manuscript No: JCTM-26-6260 (R); Published: October 23, 2026

Citation: NuggedAlla MA, Ali AM (2026). Anatomical Variations of the Frontal Sinuses in Sudanese Children. J. Clin. Transnatl. Med. Sci. Vol.1 Iss.1, October (2026), pp:23-29.

Copyright: © 2026 Motaz A. NuggedAlla, Amir Mohamed Ali. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

ABSTRACT

Background

The frontal sinuses are paranasal air spaces within the frontal bone that exhibit considerable morphological variation across populations, age groups, and sexes. Understanding these variations is clinically significant for pediatric endoscopic sinus surgery, forensic identification, and anthropological studies.

Objective

This study was designed to identify and compare the anatomical variations of the frontal sinuses in Sudanese children, with respect to gender and age, using mento-vertical skull radiographs.

Methods

A descriptive cross-sectional radiographic study was conducted on 78 Sudanese children (44 males, 34 females) aged 1-16 years, categorized into three age groups: A (1-5 years), B (6-10 years), and C (11-16 years). Mento-vertical radiographs were obtained from radiological centers in Khartoum state hospitals. Vertical and transverse diameters of the right and left frontal sinus chambers were measured, and chamber perimeter was traced and measured. Septum number, position, chamber features, and size asymmetry were recorded and analyzed in relation to age and sex.

Results

The frontal sinus was present in 88.5% of children, with bilocular chambers (53%) being the most common feature, followed by polylocular (22%) and monolocular (14%) configurations. A bony septum was present in 74% of cases, with a single septum being most frequent (52.6%). Septal position was straight/median in 62.3%, deviated to the right in 26.0%, and to the left in 11.7%. The left chamber was larger than the right in 75.0% of cases, symmetrical in 11.8%, and right-dominant in 13.2%. Age-related analysis revealed that bilocular features were dominant in group C (11-16 years), while monolocular features were more common in group B (6-10 years). The left-sided predominance was consistent across both sexes and older age groups.

Conclusion

This study provides normative baseline data on frontal sinus morphology in Sudanese children. The findings have clinical implications for surgical planning and may serve as reference data for future comparative and forensic studies. Further research using advanced imaging modalities such as CT or CBCT with larger sample sizes is recommended to validate and extend these observations.

Keywords: Frontal Sinuses; Variations; Sudanese Children; Paranasal Sinuses; Sexual Dimorphism

INTRODUCTION

The paranasal sinuses have long interested anatomists and clinicians due to their unclear functional significance and clinical importance [1]. These air-filled cavities, located within the bones of the skull and face, serve multiple proposed functions including warming and humidifying inspired air, providing resonance to the voice, reducing skull weight, and producing mucus that traps inhaled pathogens [2]. The frontal sinuses, specifically, are paired spaces within the frontal bone that develop as extensions of the nasal cavity and exhibit considerable morphological variation across individuals and populations [3].

The embryonic development of the frontal sinuses follows a predictable but highly variable pattern. Unlike the maxillary and ethmoid sinuses, which are already developed to a certain extent at birth, the frontal sinuses are typically rudimentary or absent in neonates and begin pneumatization around the second to third year of life [4]. Recent three-dimensional imaging studies have demonstrated that frontal sinus volume growth occurs most rapidly between 2-10 years of age, with growth continuing until approximately 20 years of age [5]. This prolonged developmental period makes the frontal sinuses particularly sensitive to age-related changes and population-specific variation.

The clinical relevance of frontal sinus anatomy has been substantially enhanced by the advent of endoscopic sinus surgery, which has become the standard of care for pediatric sinusitis and other sinonasal pathologies [1]. Knowledge of morphological variations is essential for surgeons to navigate the complex anatomy of the frontal recess and avoid complications such as cerebrospinal fluid leaks, orbital injury, and incomplete disease clearance. The frontal sinus drainage pathway, which traverses the frontal recess and ethmoidal infundibulum, is anatomically complex and highly variable, with individual variations in the attachment patterns of the uncinate process and the presence of frontal cells significantly affecting surgical accessibility [6].

Radiographic evaluation of the paranasal sinuses has evolved considerably since the discovery of X-rays by Roentgen in 1895 and their subsequent application to sinus diagnosis in 1896 [7]. While conventional radiography, particularly the mento-vertical (submentovertex) view, has historically been used to assess frontal sinus morphology, modern imaging techniques such as computed tomography (CT) and cone-beam CT (CBCT) provide superior anatomical detail and three-dimensional volumetric data [8]. CT imaging has become the gold standard for preoperative evaluation, allowing detailed assessment of sinus anatomy, identification of anatomical variants, and detection of pathology [8,9].

Sexual dimorphism in frontal sinus size has been a subject of considerable research interest, with implications for forensic identification and anthropological studies. Several studies have reported that males tend to have larger frontal sinuses than females. A recent study using CBCT images from 1,000 Brazilian subjects found that males exhibited significantly higher values for height, width, and anteroposterior length of

the frontal sinus compared to females [3,7], with both predictive formulas and artificial neural networks demonstrating sexual dimorphism with accuracy rates of 73.5% and 76.0%, respectively.

However, other studies, including research on South African Khoe-San populations, have found no significant sexual dimorphism, suggesting population-specific patterns [10].

Population-specific variation in frontal sinus morphology is well documented. A CT-aided study of 317 Sudanese patients found extensive pneumatization of the frontal sinus in 37% of cases, a rudimentary frontal sinus in 11%, and absence in 12% [9]. A separate Sudanese CT study of 94 subjects (57 males, 37 females) demonstrated that the left frontal sinus was consistently larger than the right, with males showing larger dimensions than females. These findings highlight the importance of establishing population-specific normative data for clinical and forensic applications.

In spite of these advances, comprehensive data on frontal sinus morphology in Sudanese children remain limited. The present study addresses this gap by providing a detailed radiographic analysis of frontal sinus variations in a pediatric Sudanese population, examining chamber features, septal anatomy, size asymmetry, and their relationships with age and sex.

MATERIALS AND METHODS

Study Design and Setting

This was a descriptive cross-sectional radiographic study conducted at three radiological centers in Khartoum state: Khartoum Hospital, Omdurman Pediatric Hospital, and Jaafar Ibn Auf Hospital. The study was carried out between November 2010 and July 2011.

Study Population

A total of 78 mento-vertical skull radiographs from Sudanese children aged 1-16 years were analyzed. The sample comprised 44 males (56%) and 34 females (44%). Subjects were categorized into three age groups: Group A (1-5 years), Group B (6-10 years), and Group C (11-16 years).

Inclusion Criteria

- Sudanese children aged between 1 year and 16 years
- Mento-vertical skull radiographs obtained during routine clinical investigation
- Radiographs of sufficient quality for anatomical assessment

Exclusion Criteria

- Age less than 1 year or above 16 years
- History of sinusitis
- Bone pathology or major illnesses
- History of sinus trauma or surgery
- Radiographs with artifacts obscuring the frontal sinus region

Ethical Considerations

The study was approved by the Faculty of Medicine and Health Sciences Research Committee at Alzaiem Alazhari University, Khartoum state. Verbal informed consent was obtained from the parents or guardians of all participating children in accordance with institutional guidelines

Radiographic Technique

Standardized mento-vertical skull radiographs were obtained with an X-ray machine-to-film distance of 80 cm. Radiographs were reviewed on an illuminated X-ray viewer.

Image Analysis

Vertical and transverse diameters of the right and left frontal sinus chambers were measured in centimeters using a calibrated ruler. Chamber perimeter was traced using a thread and then measured. Each dimension was measured three times by two experienced radiological assistants who were blinded to each other's measurements. The following parameters were recorded for each subject:

- Presence or absence of frontal sinuses
- Number of chambers (monolocular, bilocular, polylocular, or absent)
- Number and position of bony septa (straight/median, deviated to right, deviated to left)

Age Group	Frequency	Percentage
1 – 5 yrs (A)	7	9%
6 – 10 yrs (B)	31	40%
11 – 16 yrs (C)	40	51%
Total	78	100%

Table 1: Distribution of children according to Age

Sex	Frequency	Percentage
Male	44	56%
Female	34	44%
Total	78	100%

Table 2: Sex distribution

Frontal Sinus Presence and Chamber Features

Frontal sinuses were present in 69 of 78 children (88.5%) and absent in 9 children (11.5%). Among children with visible sinuses, the chamber feature distribution was: bilocular in 41

- Chamber size comparison (right larger, left larger, or symmetrical)

Statistical Analysis

Data were entered and analyzed using SPSS version 20.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics (frequencies, percentages, means, and standard deviations) were used to summarize the data. Cross-tabulations were performed to examine relationships between anatomical parameters and demographic variables (age group and sex). Due to the descriptive nature of the study, inferential statistical tests were not applied.

RESULTS

Age and Sex Distribution

The study included 78 children with a mean age of approximately 9 years (range: 3-16 years). Although the eligibility criteria specified ages 1-16 years, the youngest subject in the analyzed radiographs was 3 years old. Age group distribution was as follows: Group A (1-5 years) comprised 7 children (9%), Group B (6-10 years) comprised 31 children (40%), and Group C (11-16 years) comprised 40 children (51%). The sex distribution was 44 males (56%) and 34 females (44%), as shown in Tables 1,2

children (53%), polylocular in 17 children (22%), and monolocular in 11 children (14%). The 9 children (11.5%) with absent sinuses were primarily from Group A (5 children) and Group B (2 children), with only 2 from Group C. as shown in Tables 3.

No. of septum	Female	Male	Total	%
One septum	28	13	41	52%
Two septa	4	11	15	19%
More than two	0	2	2	3%
Absence	2	18	20	26%
Total	34	44	78	100%

Table 3: Septum number in relation to sex

Chamber Features by Age

Bilocular chambers were most frequent in Group C (30 of 40 children, 75%), monolocular chambers were mainly found in Group B (9 of 31 children, 29%), and polylocular chambers

were distributed between Groups B and C (9 and 8 children, respectively). Sinus absence was most common in Group A (5 of 7 children, 71%). as shown in Table 4

No. of septum	Group A	Group B	Group C	Total	%
One septum	Absent	11	30	41	52%
Two septa	Absent	9	6	15	19%
More than two septa	Absent	Absent	2	2	3%
Absence	7	11	2	20	26%
Total	7	31	40	78	100%

Table 4: Septum number in relation to age

Chambers feature	Group A	Group B	Group C	Total
Monolocular	2	9	Absent	11
Bilocular	Absent	11	30	41
Polylocular	Absent	9	8	17
Absent	5	2	2	9
Total	7	31	40	78

Table 5: Relation between chamber feature and age categories

Chamber Features by Sex

Bilocular chambers were more common in females (28 of 34, 82%) than in males (13 of 44, 30%). Monolocular chambers

were more frequent in males (10 of 44, 23%) than females (1 of 34, 3%). Polylocular chambers were also more common in males (14 of 44, 32%) than females (3 of 34, 9%). as shown in Table 6

Chambers feature	Male	Female	Total
Monolocular	10	1	11
Bilocular	13	28	41
Polylocular	14	3	17
Absent	7	2	9
Total	44	34	78

Table 6: Distribution of children by sex according to chambers feature

Chambers size	Group A	Group B	Group C	Total
Greater in Rt side	0	5	4	9
Greater in Lt side	2	29	30	61
Symmetrical	1	0	7	8
Total	3	34	41	78

Table 7: Relation between chamber size and age categorie

Bony Septum Characteristics

A bony septum was present in 58 children (74%) and absent in 20 children (26%). Among those with septa:

Septum Number: Single septum in 41 children (52.6%), two septa in 15 children (19.2%), more than two septa in 2 children (2.6%), and no septum in 20 children (25.6%).

Septum Position: Of the 78 individual septa with positional data, 48 (62.3%) were straight/median, 20 (26.0%) were deviated to the right, and 10 (11.7%) were deviated to the left.

Septum Number by Age: Single septum was most common in Group C (30 of 40, 75%), two septa were distributed between Groups B and C (9 and 6 children, respectively), and absence of septum was most common in Groups A and B (7 and 11 children, respectively).

Septum Number by Sex: Single septum was more common in females (28 of 34, 82%) than in males (13 of 44, 30%). Two septa were more common in males (11 of 44, 25%) than females (4 of 34, 12%). Absence of septum was also more common in males (18 of 44, 41%) than females (2 of 34, 6%). as shown in Tables 6,7

Chamber Size Asymmetry

Among the 78 children:

Left chamber larger: 61 children (75.0%)

Right chamber larger: 9 children (13.2%)

Symmetrical chambers: 8 children (11.8%)

By Age: Left-sided predominance was observed in both Group B (29 of 31, 94%) and Group C (30 of 40, 75%).

Chambers size	Male	Female	Total
Greater in Rt side	9	0	9
Greater in Lt side	30	31	61
Symmetrical	4	4	8
Total	43	35	78

Table 8: Distribution of children by sex according to chambers size

Symmetrical chambers were most common in Group C (7 of 40, 18%), while right-sided predominance was observed in 5 children from Group B and 4 from Group C.

By Sex: Left-sided predominance was observed in both sexes (30 of 44 males, 68%; 31 of 34 females, 91%). Right-sided predominance was seen only in males (9 of 44, 20%).

Symmetrical chambers were equally distributed (4 males, 4 females). as shown in Table 8

Sexual Dimorphism

Our observation that frontal sinus chambers were slightly larger in males than females, although not formally tested with quantitative measurements, is consistent with the majority of the literature. Szilvassy reported that between ages 14-15 years, male frontal sinuses exceed female ones in size, with complete formation occurring by age 189. Recent advanced imaging studies have provided strong evidence for sexual dimorphism: a CBCT study of 1,000 subjects found that males exhibited significantly larger height, width, and anteroposterior length measurements compared to females, with artificial neural network models achieving 76% accuracy in sex estimation. Similarly, a Sudanese CT study of 94 adults found that males had consistently larger frontal sinus dimensions than females.

However, it is important to note that sexual dimorphism is not universally observed across all populations. A study of South African Khoe-San skeletal remains found no significant sex differences in frontal sinus volume, suggesting population-specific patterns that may reflect genetic or environmental influences [13]. The present study supports the general trend toward male predominance in sinus size but emphasizes the need for quantitative volumetric studies using CT or CBCT to confirm these findings in the Sudanese pediatric population.

Chamber Feature and Septal Variations

The high prevalence of bilocular chambers (53%) with a single bony septum (52.6%) in our study is consistent with the typical anatomy described in the literature. The finding that septal position was most commonly straight/median (62.3%). However, the relatively high proportion of septal deviation to the right (26.0%) compared to the left (11.7%) is an interesting observation that may have clinical implications for surgical planning.

The presence of polylocular chambers (22%) in our study, particularly in older children and males, suggests that the frontal sinus continues to undergo complex septation and subdivision during development. This finding is consistent with the understanding that the frontal sinus is a dynamic structure that continues to remodel and expand throughout childhood and adolescence

DISCUSSION

This study provides the first comprehensive radiographic analysis of frontal sinus anatomical variations in Sudanese children, with specific attention to chamber features, septal morphology, and size asymmetry in relation to age and sex. The findings contribute to the growing body of literature on population-specific frontal sinus morphology and have implications for clinical practice, particularly in pediatric endoscopic sinus surgery.

Frontal Sinus Development and Age-Related Changes

The age distribution of frontal sinus presence in our study with sinus absence most common in the youngest age group (1-5 years) and increasing prevalence in older children is consistent with established developmental patterns. The frontal sinus typically begins pneumatization around the second to third year of life and becomes radiologically visible between 3-6 years of age [10]. Our finding that frontal sinuses were present in only 29% of children in Group A (1-5 years) but in over 90% of children in Groups B and C aligns with previous reports. A study by Pobornikova demonstrated that frontal sinus growth begins at approximately 13 months of age and proceeds similarly in both sexes until puberty, after which sex-specific growth patterns emerge [11]. More recent three-dimensional CT studies have confirmed that frontal sinus volume continues to increase until approximately 20 years of age, with the most rapid growth occurring between 2-10 years [12].

The predominance of bilocular chambers (53%) in our study population, with increasing prevalence in older children, suggests progressive pneumatization and septation of the developing frontal sinus with age. This finding is consistent with the concept that the frontal sinus undergoes morphological maturation throughout childhood and adolescence, with septal development reflecting the complex interactions between bone resorption and deposition during sinus expansion.

Left-Sided Predominance

left frontal sinus was consistently larger than the right, with mean left width (22.71 mm) exceeding right width (21.56 mm), and left height (15.40 mm) exceeding right height (14.81 mm).

The mechanism underlying this consistent left-sided predominance is not fully understood but may relate to asymmetric patterns of cranial bone growth, differential pneumatization rates, or functional influences such as nasal airflow patterns. This observation has practical implications for forensic identification, as left-right asymmetry can serve as a unique individualizing feature, and for surgical planning, where understanding the typical patterns of sinus asymmetry can aid in preoperative assessment.

Clinical Implications

The anatomical variations documented in this study have several important clinical implications. Knowledge of the normal range of chamber features, septal morphology, and size asymmetry is essential for pediatric endoscopic sinus surgeons to safely navigate the frontal recess and avoid complications. The high prevalence of septal deviation (37.7% non-median) underscores the need for careful preoperative imaging assessment to identify potentially challenging anatomical variants.

The finding that frontal sinuses are absent in 11.5% of children, particularly in the youngest age group, is consistent with the known developmental timeline and serves as a reminder that the presence and extent of sinus pneumatization should be evaluated on an individual basis. The association of bilocular chambers with older age and female sex, and monolocular/polylocular chambers with male sex, may reflect sex-specific patterns of sinus growth and development that warrant further investigation.

However, the use of radiography in this study is justified by practical considerations: CT imaging is rarely performed in pediatric patients without specific clinical indications due to radiation exposure concerns, making radiographic studies an important source of normative anatomical data, particularly in resource-limited settings where advanced imaging may be less accessible.

Study Limitations

Several limitations of this study should be acknowledged. First, the sample size of 78 children, while adequate for a descriptive study, limits the generalizability of findings and precludes robust statistical analysis of subgroup differences. The small number of children in Group A (n=7) particularly limits conclusions about early development. Second, the use of radiographs rather than CT precludes volumetric analysis and may have underestimated the complexity of sinus morphology. Third, the lack of inter- and intra-observer reliability testing for the measurements represents a methodological limitation. Fourth, the absence of inferential statistical testing means that observed differences between groups cannot be formally confirmed as statistically significant. Finally, the study did not

include clinical correlation, so the clinical significance of the observed variations remains to be established.

CONCLUSION

This radiographic study of 78 Sudanese children provides baseline normative data on frontal sinus anatomical variations in relation to age and sex. The frontal sinus was present in 88.5% of children, with bilocular chambers being the most common feature (53%), followed by polylocular (22%) and monolocular (14%) configurations. A bony septum was present in 74% of children, most commonly single (52.6%) and straight/median in position (62.3%). The left chamber was larger than the right in 75% of cases, a finding consistent across both sexes and age groups. Age-related analysis revealed that bilocular features and increasing chamber complexity were associated with older age, while sinus absence was most common in younger children. The trend toward larger sinuses in males, while not formally confirmed with quantitative measurements, is consistent with the majority of the literature.

These findings contribute to the understanding of frontal sinus development and variation in an understudied population and have practical implications for pediatric endoscopic sinus surgery, forensic identification, and anthropological studies. The left-sided predominance and high prevalence of septal variations are particularly notable observations that warrant further investigation. We recommend future studies using advanced imaging modalities (CT or CBCT) with larger sample sizes, three-dimensional volumetric analysis, and inferential statistical testing to validate and extend these findings.

REFERENCES

1. Keir J. Why do we have paranasal sinuses? *J Laryngol Otol.* 2009;123(1): 4-8.
2. Yamakawa K, Nishijima H, Koizumi M, Kondo K. Assessing volume growth of paranasal sinuses and nasal cavity in children using three-dimensional imaging software. *Auris Nasus Larynx.* 2024;51(6):917-921.
3. Oliveira JA, Borella NR, Ramos-Perez FMM, Pontual AA, Calazans MAA, Ferreira FABS, Madeiro F, Pontual MLA. Determination of sexual dimorphism with CBCT images of the frontal sinus using a predictive formula and an artificial neural network. *J Appl Oral Sci.* 2025;33:e20250049.
4. Lee S, Fernandez J, Mirjalili SA, Kirkpatrick J. Pediatric paranasal sinuses—Development, growth, pathology, & functional endoscopic sinus surgery. *Clin Anat.* 2022;35(6):745-761.
5. Szilvássy J. Development of the frontal sinuses. *Anthropol Anz.* 1981;39(2):138-149.
6. Balasubramanian S. Anatomic variants of the frontal sinus. In: *Rhinology and Skull Base Surgery.* 2009.
7. Elhassan EM, Ahmed ME, Suliman AA, Osman OO. Determination of normal frontal sinuses dimensions using computed tomography among Sudanese subjects Report. *Sudan University of Science and Technology;* 2016.
8. Triulzi F. Diagnostic imaging of the pediatric nasal cavity and paranasal sinuses. *Int J Immunopathol Pharmacol.* 2010;23(1 Suppl):41-44.
9. Dafalla SE, Seyed MA, Elfadil NA, Elmustafa OM, Hussain Z. A computed tomography-aided clinical report on anatomical variations of the paranasal sinuses. *Int J Med Res Health Sci.* 2017;6(2):24-33.
10. Lee S, Fernandez J, Mirjalili SA, Kirkpatrick J. Pediatric paranasal sinuses—Development, growth, pathology, & functional endoscopic sinus surgery. *Clin Anat.* 2022;35(6):745-761.

11. Pobornikova S. An x-ray investigation of the development of the frontal sinuses in children. *Folia Med (Plovdiv)*. 1974;16(4):213-220.
12. Park JA, Lee YJ, Yeo IS, Koh KS, Song WC. Three-dimensional linear and volumetric computed tomography analysis of the frontal sinus. *Anat Cell Biol*. 2022;55(2):142-147.
13. Grine FE, Post NW, Greening V, Crevecoeur I, Billings BK, Meyer A, Holt S, Black W, Morris AG, Veeramah KR, Mongle CS. Frontal sinus size in South African Later Stone Age Holocene Khoe-San. *Anat Rec (Hoboken)*. 2024.