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Age-Related Morphometric Characteristics Of The Frontal Sinuses In Children Of The Bukhara Region

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ABSTRACT

The frontal sinuses are highly variable anatomical structures whose morphology changes significantly with age, sex, and environmental factors. Reliable data on their development in childhood and adolescence remain limited, especially in regional populations. Cone-beam computed tomography (CBCT) provides accurate three-dimensional visualization and allows detailed morphometric analysis of the sinuses at minimal radiation exposure. The aim of study was to investigate age-related morphometric characteristics of the frontal sinuses in children and adolescents from the Bukhara region using CBCT. A total of 516 clinically healthy individuals (240 boys, 276 girls) aged 4–18 years were examined. CBCT scans were performed in standing position, with standardized head fixation. Morphometric parameters (length, width, depth, volume), shape, and pneumatization frequency were evaluated using OneClinic 3D Viewer software. Statistical analysis was performed in Microsoft Excel 2016 and IBM SPSS Statistics 20, applying parametric and non-parametric methods (t-test, Fisher's F-test, $p<0.05$). Frontal sinuses became measurable from the age of 4, with a sharp increase in pneumatization frequency by 6–7 years. Intensive growth occurred during school and adolescent periods (8–16 years), followed by stabilization at 17–18 years. Boys demonstrated significantly larger dimensions and volumes than girls, particularly during puberty ($p<0.05$). A left-sided dominance was observed, more pronounced in males, whereas girls exhibited relatively symmetric development. Sinus shape evolved with age, from round/oval in early childhood to more diverse forms (oval, triangular, irregular) in adolescence. CBCT proved to be an optimal method for age-related morphometric evaluation of the frontal sinuses, providing accurate volumetric and shape assessment. The study established normative data for the Bukhara region population, confirming earlier and more intensive development of the left sinus, significant sexual dimorphism, and regional morphological features. These findings are relevant for otorhinolaryngology, maxillofacial surgery, forensic identification, and anthropological studies.

Keywords: frontal sinuses, age-related morphology, cone-beam computed tomography, pneumatization, asymmetry, sexual dimorphism

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1. INTRODUCTION

The frontal sinuses belong to the paranasal air-filled structures of the facial skeleton and exhibit a high degree of anatomical variability. Their size, shape, and degree of pneumatization vary considerably depending on age, sex, and individual characteristics. The study of age-related developmental patterns of the frontal sinuses is of particular interest to otorhinolaryngology, maxillofacial surgery, dentistry, and forensic medicine, as these data are essential for accurate diagnosis, surgical planning, and identification procedures.

Traditional radiographic methods of paranasal sinus visualization have limited diagnostic value due to overlapping anatomical structures and low morphometric accuracy. In recent years, cone-beam computed tomography (CBCT) has gained wide application in clinical practice because of its low radiation dose, high spatial resolution, and ability to provide three-dimensional reconstructions of the studied region. These advantages make CBCT the optimal method for morphometric evaluation of the paranasal sinuses, including the frontal sinuses.

Despite the availability of both domestic and international studies devoted to the morphology of the frontal sinuses, data on age-related changes obtained using CBCT remain limited. In particular, regional characteristics of pneumatization and morphometry of the frontal sinuses in populations of different territories, including the Bukhara region, remain insufficiently studied.

Objective: To determine the age-related patterns of development and morphometric variability of the frontal sinuses in the population of the Bukhara region through the analysis of cone-beam computed tomography (CBCT) data.

Materials and Methods. To identify the age-related patterns of frontal sinus growth, a study was conducted on cranial tomograms of practically healthy residents of the Bukhara region. The study included 516 individuals of both sexes, aged 1 to 18 years. The examinations were performed in the Department of Radiological Computed Tomography at the private clinic *LOROSTOM* (Bukhara region).

Visualization was performed using cone-beam computed tomography (CBCT). Scanning was carried out in the standing position, with the patient's head fixed in a headrest. During the examination, the emitter system and detector synchronously completed a 360° rotation around the patient's head. The average scanning time was approximately 20 seconds, which allowed for high-quality three-dimensional reconstructions with minimal radiation exposure.

For more precise characterization and comparative assessment of the morphometric parameters of the frontal sinuses, the subjects (240 boys and 276 girls) were divided into age groups according to the periodization adopted at the VII All-Union Conference on Age Morphology, Physiology, and Biochemistry.

For each participant, an individual record card was created, which included information on age, sex, ethnicity, and cranial shape. The morphometric characteristics of the frontal sinuses were determined using the following parameters: length, width, and volume.

Morphometric parameters of the frontal sinuses were assessed on reconstructed tomograms using standard anatomical landmarks. Length was measured in the sagittal projection (from the upper to the lower wall of the sinus), width — in the frontal projection (between the medial and lateral walls), and depth — in the axial projection (from the anterior to the posterior wall). Volume was automatically calculated using the OneClinic 3D Viewer software based on three-dimensional reconstruction.

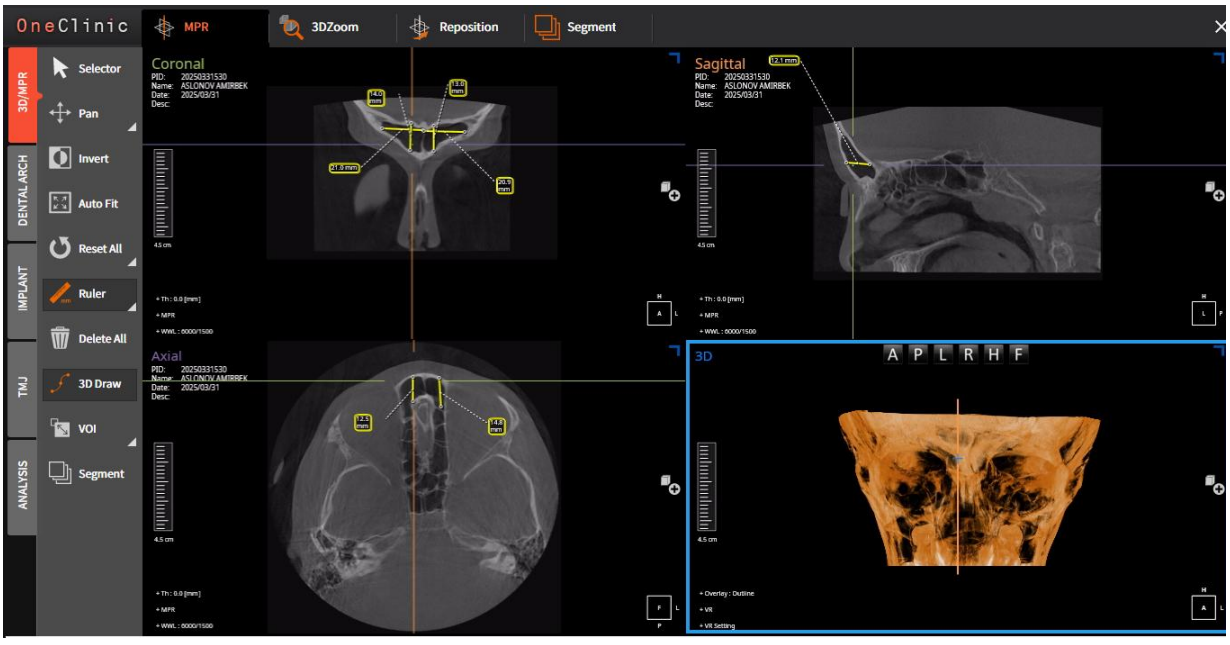

Figure 1. Scheme of frontal sinus measurements is presented.

The obtained data were processed using the OneClinic 3D Viewer software, which provides three-dimensional reconstruction, multiplanar visualization, and the possibility of detailed analysis of the paranasal sinus structures. Statistical processing was performed on a personal computer using Microsoft Office Excel 2016 and IBM SPSS Statistics 20 packages (operating system: Windows 10 Pro).

Both parametric and non-parametric methods of statistical analysis were applied. The arithmetic mean (M), standard deviation (σ), standard error of the mean (m), as well as relative values (frequency, %) were calculated. For comparison of mean values, Student's *t*-test and Fisher's *F*-test were used under conditions of normal distribution, along with the

probability of error (p). To assess the statistical significance of the calculated criteria, critical values and accepted levels of significance (p) were applied.

2. RESULTS AND DISCUSSION

All collected results are presented with consideration of age, since reliable morphometric measurements of the frontal sinuses can only be obtained starting from the age of four, when the sinuses begin to form.

In boys from the Bukhara region aged 4–7 years, the dimensions of the frontal sinuses were minimal and characterized by high variability. The length of the right sinus ranged from 3.2 to 10.0 mm (7.2 ± 0.35 mm), width — 4.1–15.5 mm (11.0 ± 0.61 mm), depth — 2.3–11.1 mm (7.7 ± 0.44 mm), volume — 0.015–0.77 cm³ (0.37 ± 0.45 cm³). For the left sinus, the values were: length — 3.5–10.2 mm (7.6 ± 0.33 mm), width — 5.1–15.4 mm (10.9 ± 0.54 mm), depth — 2.1–12.8 mm (7.9 ± 0.44 mm), volume — 0.019–0.77 cm³ (0.42 ± 0.43 cm³).

In girls of the same age group, the right sinus showed smaller values: length — 2.1–7.9 mm (4.9 ± 0.36 mm), width — 4.5–16.3 mm (9.2 ± 0.71 mm), depth — 1.2–11.8 mm (7.2 ± 0.58 mm), volume — 0.027–0.75 cm³ (0.19 ± 0.39 cm³). The left sinus demonstrated: length — 3.3–9.1 mm (6.2 ± 0.27 mm), width — 4.6–18.1 mm (10.1 ± 0.61 mm), depth — 3.2–12.2 mm (8.2 ± 0.47 mm), volume — 0.032–0.91 cm³ (0.31 ± 0.41 cm³) (Table 1).

Shape: At this age, the frontal sinuses were most often rounded or oval with indistinct contours. Symmetry was generally preserved, and asymmetric forms were rare.

Age group 8–12 years.

In boys, the right sinus had a length of 7.0–14.8 mm (10.4 ± 0.27 mm), width — 12.1–23.5 mm (17.9 ± 0.38 mm), depth — 8.3–14.9 mm (11.8 ± 0.19 mm), volume — 0.42–2.38 cm³ (1.21 ± 0.65 cm³). On the left side, the values were higher: length — 7.9–16.2 mm (11.5 ± 0.28 mm), width — 12.1–24.2 mm (19.1 ± 0.40 mm), depth — 8.7–16.6 mm (12.1 ± 0.21 mm), volume — 0.53–2.88 cm³ (1.46 ± 0.76 cm³).

In girls, the right sinus had a length of 4.6–13.5 mm (8.1 ± 0.19 mm), width — 10.1–20.5 mm (12.9 ± 0.30 mm), depth — 6.8–13.4 mm (11.1 ± 0.16 mm), volume — 0.26–1.75 cm³ (0.63 ± 0.33 cm³). The left sinus showed a length of 5.4–13.5 mm (9.6 ± 0.21 mm), width — 10.1–24.5 mm (15.6 ± 0.38 mm), depth — 7.4–12.8 mm (11.1 ± 0.15 mm), volume — 0.36–1.87 cm³ (0.88 ± 0.41 cm³).

Shape: In this age group, forms became more diverse: in addition to rounded, oval and triangular types were observed. The sinus contours became more distinct, and slight asymmetry was sometimes noted, manifested by an elongated shape on one side.

Age group 13–16 years.

In boys, the right sinus measurements were: length — 13.0–16.0 mm (14.5 ± 0.15 mm), width — 12.6–23.3 mm (16.9 ± 0.39 mm), depth — 19.3–32.0 mm (25.1 ± 0.47 mm), volume — 1.62–7.73 cm³ (3.61 ± 0.25 cm³). On the left: length — 13.5–23.0 mm (17.6 ± 0.38 mm), width — 22.5–35.0 mm (26.4 ± 0.47 mm), depth — 12.9–22.5 mm (16.1 ± 0.39 mm), volume — 2.41–8.5 cm³ (4.16 ± 0.27 cm³).

In girls aged 12–15 years, the right sinus had a length of 7.9–18.1 mm (13.0 ± 0.28 mm), width — 16.5–27.0 mm (21.4 ± 0.31 mm), depth — 10.9–17.5 mm (13.4 ± 0.19 mm), volume — 0.94–3.59 cm³ (1.98 ± 0.77 cm³). The left sinus values were: length — 8.9–18.3 mm (14.5 ± 0.26 mm), width — 15.8–28.9 mm (24.3 ± 0.31 mm), depth — 11.4–21.3 mm (15.0 ± 0.28 mm), volume — 0.92–4.26 cm³ (2.84 ± 0.11 cm³).

During adolescence, the greatest diversity in frontal sinus forms was observed. In boys, oval and triangular shapes predominated, often with vertical elongation. In girls, the sinuses were more compact, predominantly oval and rounded. Asymmetry was common: for example, one sinus could be triangular, while the other was oval.

Age group 17–18 years.

In young men, the right frontal sinus had a length of 19.9–23.5 mm (22.2 ± 0.17 mm), width — 29.8–35.1 mm (32.8 ± 0.24 mm), depth — 19.5–23.5 mm (21.7 ± 0.18 mm), volume — 6.46–9.52 cm³ (8.28 ± 0.15 cm³). On the left side, the measurements were: length — 20.6–24.4 mm (22.8 ± 0.17 mm), width — 31.0–38.1 mm (35.2 ± 0.35 mm), depth — 20.2–25.0 mm (22.7 ± 0.23 mm), volume — 7.31–11.3 cm³ (9.59 ± 0.22 cm³).

In young women, the right frontal sinus had a length of 14.1–18.5 mm (16.4 ± 0.13 mm), width — 21.2–33.5 mm (28.1 ± 0.49 mm), depth — 13.9–17.7 mm (15.6 ± 0.13 mm), volume — 2.51–5.12 cm³ (3.76 ± 0.89 cm³). The left sinus measurements were: length — 15.2–18.7 mm (16.8 ± 0.14 mm), width — 24.6–33.8 mm (29.8 ± 0.35 mm), depth — 15.1–19.6 mm (17.6 ± 0.12 mm), volume — 3.51–5.81 cm³ (4.63 ± 0.88 cm³).

By the age of 17–18 years, the frontal sinuses had reached their final individual morphology. In young men, triangular and irregular forms with additional septa and compartments were more common, while in young women oval forms with more pronounced symmetry predominated.

Table 1.Morphometric parameters of the frontal sinuses in children from the Bukhara region by age group (M±σ, mm; cm³).

Age group	Gender	Side	Length, mm	Width, mm	Depth, mm	Volume, cm³
4–7 years	Boys	Right	7.2±0.35	11.0±0.61	7.7±0.44	0.37±0.45
		Left	7.6±0.33	10.9±0.54	7.9±0.44	0.42±0.43
	Girls	Right	4.9±0.36	9.2±0.71	7.2±0.58	0.19±0.39
		Left	6.2±0.27	10.1±0.61	8.2±0.47	0.31±0.41
8–12 years	Boys	Right	10.4±0.27	17.9±0.38	11.8±0.19	1.21±0.65
		Left	11.5±0.28	19.1±0.40	12.1±0.21	1.46±0.76
	Girls	Right	8.1±0.19	12.9±0.30	11.1±0.16	0.63±0.33
		Left	9.6±0.21	15.6±0.38	11.1±0.15	0.88±0.41
13–16 years	Boys	Right	14.5±0.15	16.9±0.39	25.1±0.47	3.61±0.25
		Left	17.6±0.38	26.4±0.47	16.1±0.39	4.16±0.27
	Girls	Right	13.0±0.28	21.4±0.31	13.4±0.19	1.98±0.77
		Left	14.5±0.26	24.3±0.31	15.0±0.28	2.84±0.11
17–18 years	Boys	Right	22.2±0.17	32.8±0.24	21.7±0.18	8.28±0.15
		Left	22.8±0.17	35.2±0.35	22.7±0.23	9.59±0.22
	Girls	Right	16.4±0.13	28.1±0.49	15.6±0.13	3.76±0.89
		Left	16.8±0.14	29.8±0.35	17.6±0.12	4.63±0.88

Note: The mean values of morphometric parameters (M±σ) are presented. Statistically significant differences between sexes ($p<0.05$) were established starting from adolescence.

The frequency of pneumatization in younger age groups (4–6 years). At the age of 4, visualization of the frontal sinuses was rare; however, the left side was more frequently identified: in boys — in 14.3% of cases, the right side — only in 7.1%. In girls, a similar trend was observed: the left sinus — in 25.0%, the right — in 6.3%.

By the age of 5, the frequency of detection remained low, amounting to about 13–25%, with predominance of the left side.

By the age of 6, a sharp increase in the frequency of pneumatization was noted: in boys, the left sinus was visualized in 71.4% of cases, while the right only in 35.7%. In girls, the same tendency was observed: the left — in 40%, the right — in 26.7%.

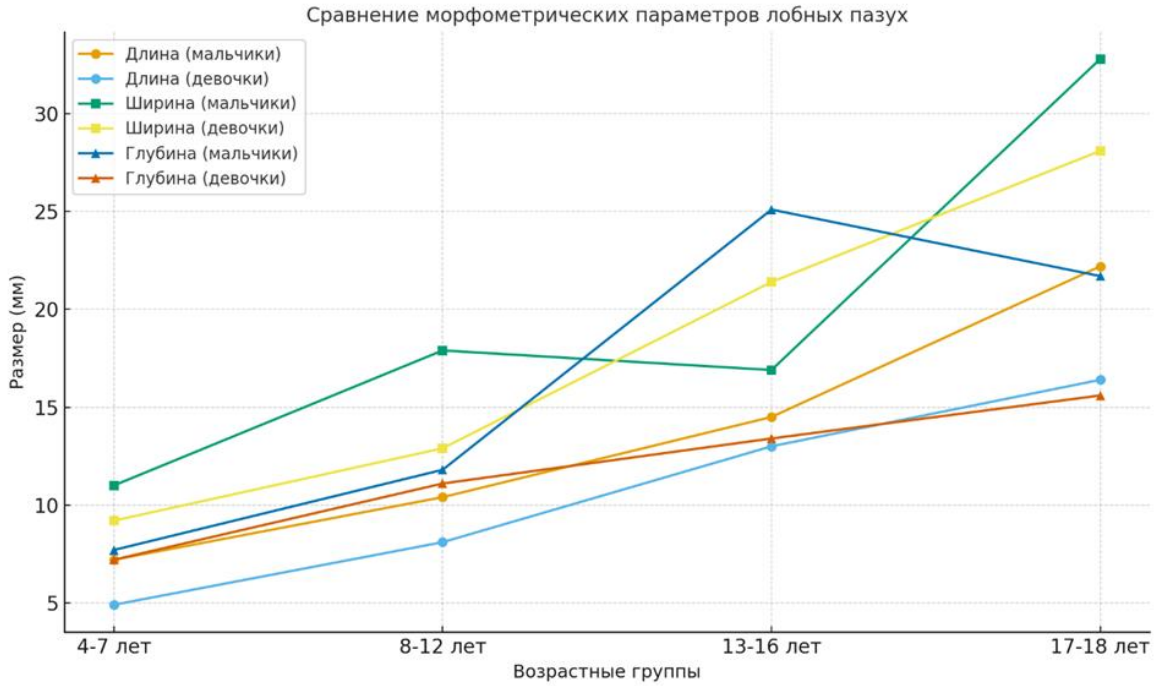

Figure 2. Comparative analysis of morphometric parameters of the frontal sinuses in boys and girls across different age groups.

Thus, the development of the frontal sinuses in children aged 4–6 years is characterized by earlier and more pronounced pneumatization of the left side, whereas the right sinus develops more slowly.

Table 2. Age-related dynamics of morphometric parameters of the frontal sinuses in children of the Bukhara region (M±σ, mm; cm³).

Age (years)	Gender	Height (mm)	Width (mm)	Depth (mm)	Volume (cm³)
4	Boys	3.80	5.45	2.35	0.026
4	Girls	4.93	8.00	5.26	0.121
5	Boys	4.60	8.28	4.73	0.090
5	Girls	4.55	8.35	5.09	0.110
6	Boys	7.12	8.59	7.15	0.265
6	Girls	5.30	9.24	6.84	0.205
7	Boys	8.23	12.74	8.95	0.510
7	Girls	5.95	10.26	8.91	0.315
8	Boys	8.80	13.16	10.32	0.625
8	Girls	8.03	11.94	10.32	0.530
9	Boys	9.54	18.97	11.47	1.090
9	Girls	8.49	13.67	10.86	0.660
10	Boys	10.03	19.19	12.26	1.190

Age (years)	Gender	Height (mm)	Width (mm)	Depth (mm)	Volume (cm^3)
10	Girls	8.95	14.64	11.06	0.770
11	Boys	12.54	19.56	12.64	1.620
11	Girls	9.81	16.40	11.82	1.015
12	Boys	13.85	21.84	13.72	2.170
12	Girls	11.16	20.19	12.31	1.480
13	Boys	14.79	23.13	14.01	2.515
13	Girls	13.77	22.99	13.64	2.280
14	Boys	15.05	23.38	13.99	2.590
14	Girls	14.26	23.68	14.88	2.670
15	Boys	18.55	25.81	14.72	3.685
15	Girls	15.47	24.09	15.73	3.090
16	Boys	20.92	31.17	20.36	6.960
16	Girls	16.08	24.50	16.35	3.380
17	Boys	21.99	32.73	21.17	8.000
17	Girls	16.50	30.43	16.80	4.430
18	Boys	22.92	35.19	23.13	9.785
18	Girls	16.93	30.75	16.67	4.550

3. DISCUSSION

The obtained data demonstrate a consistent age-related development of the frontal sinuses in children of the Bukhara region. Formation of the sinuses begins at the age of 4 years; by 6–7 years, there is a sharp increase in their detectability, with the left side developing more actively. Subsequently, a sequential growth in sinus length, width, depth, and volume is observed, with marked acceleration during school age and adolescence. By 17–18 years, the size and volume stabilize, approaching adult values. At the same time, in boys, the dimensions and volume of the sinuses significantly exceed those in girls, while asymmetry is expressed as left-sided dominance.

Our results are consistent with data reported in international literature. For example, Motawei et al. (2016) highlighted the high informativeness of CBCT in frontal sinus morphometry and noted substantial individual and sex-related variability, which aligns with our findings in younger age groups.

A notable contribution was made by Moore and Ross (2017), who proposed a staging system for assessing frontal sinus development in children and adolescents based on radiographs. The authors demonstrated that developmental stage could serve as an age indicator, although the ranges of stages were broad. Our CBCT-based results complement and refine their conclusions, as they enable quantitative assessment of sinus length, width, depth, and volume, as well as detection of sexual dimorphism and asymmetry, which is not possible with staging based on two-dimensional images.

Equally significant is the study by Sardi et al. (2018), which investigated the dynamics of frontal sinus volume in an Argentine population. The authors found that the sinuses become reliably measurable at around 6 years, with volume correlating to cranial and frontal parameters. Our findings largely confirm these results; however, we document the initiation of sinus formation in some children as early as 4 years. Furthermore, the use of CBCT allowed us to expand upon Sardi's conclusions by providing quantitative detail, identifying sexual dimorphism, and revealing regional features such

as left-sided dominance.

Abate et al. (2022) reported a gradual increase in frontal sinus volume during adolescence but did not find a strict correlation between sinus size and age. In contrast, our data indicate a clear age-related dynamic, expressed by marked volumetric increases at 8–12 and 13–16 years.

Denny et al. (2023) identified significant sinus asymmetry and its relationship with craniofacial parameters. Our study also revealed asymmetry, but with sex-specific differences: in boys, distinct left-sided dominance was observed, while in girls, the sinuses developed more symmetrically.

Jasso-Ramírez et al. (2023) analyzed the morphometry of paranasal sinuses in children and young adults using CT. They reported significant age-related differences and sexual dimorphism: in girls, sinus volume was greater between 5–10 years, while in boys, larger volumes were observed in older age groups; they also identified a strong correlation between right and left sinuses. Our findings are in agreement with their conclusions regarding age-related dynamics but extend them by demonstrating an earlier onset of growth (from 4 years), consistent left-sided dominance, and more pronounced differences during adolescence.

Shekar et al. (2025) confirmed the presence of sexual dimorphism, noting larger frontal sinuses in males. A similar trend was revealed in our cohort: in adolescent boys, sinus parameters significantly exceeded those of girls, confirming sex differences in the growth of the facial skeleton.

Comparison with domestic studies. Similar results were obtained in the study of Kosourov A.K. and Morozova V.V., which addressed age-related changes of paranasal sinuses in the Karelia population. The authors reported sexual variability and pronounced left-sided asymmetry of the frontal sinuses, which fully corresponds with our findings in children of the Bukhara region. Unlike their work, which employed radiographic methods, the use of CBCT in our study provided more precise morphometric indicators and allowed us to trace growth dynamics year by year. Thus, our results not only confirm the conclusions of Morozova but also deepen them through three-dimensional quantitative data and analysis of regional features.

4. CONCLUSION.

This study has revealed the patterns of age-related development of the frontal sinuses in children and adolescents of the Bukhara region based on cone-beam computed tomography (CBCT). The frontal sinuses become clearly detectable from the age of four, and by 6–7 years a rapid increase in pneumatization is observed. The most intensive growth occurs during school age and adolescence (8–16 years), while by 17–18 years the size and volume of the sinuses stabilize and approximate adult values.

Sex-related differences were also identified. In boys, a stable left-sided dominance appears from adolescence, whereas in girls asymmetry is much less pronounced and tends to diminish by late adolescence. Morphologically, younger children predominantly have round or oval sinuses, while in adolescence the variety of forms expands to include oval, triangular, and irregular shapes. Boys more frequently exhibit large, asymmetric sinuses with septa and cells, while girls show more compact and symmetric oval forms. A clear sexual dimorphism was established, with boys having significantly larger morphometric parameters than girls, especially during puberty. By the age of 17–18, the volume of the frontal sinuses in boys exceeded that of girls by 15–20%.

Regional features were also noted: in children of the Bukhara region, pneumatization of the left frontal sinus begins earlier and progresses more actively than on the right side. This left-sided dominance corresponds with findings reported by Morozova and co-authors and can be considered a regular anatomical characteristic with inter-population significance.

The use of CBCT provided high accuracy of morphometric measurements while minimizing radiation exposure. Unlike conventional radiography, CBCT makes it possible to perform three-dimensional reconstruction, objectively assess sinus shape and volume, and identify asymmetry and sex differences, which establishes it as the “gold standard” for morphological studies of paranasal sinuses in children and adolescents.

The normative data obtained in this study hold significant practical value for various fields of medicine and science. In otorhinolaryngology and maxillofacial surgery, they are important for diagnosis and treatment planning in children and adolescents. In dentistry and orthodontics, consideration of age- and sex-related differences is essential for evaluating facial skeletal harmony. In forensic medicine, morphometric parameters of the frontal sinuses can serve as an additional tool for personal identification. In anthropology, the revealed developmental patterns provide evidence of ethnic and regional variability in frontal sinus morphology.

Overall, CBCT should be regarded as the optimal method for a comprehensive assessment of frontal sinus development in relation to age, sex, and morphology

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