

EVALUATION OF MAXILLARY SINUS VOLUME IN DIFFERENT CRANIOFACIAL GROWTH PATTERNS: A RETROSPECTIVE CBCT STUDY

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ABSTRACT

Background: The maxillary sinus is an important anatomical structure that contributes to craniofacial growth and has significant implications in orthodontic diagnosis and treatment planning. Although previous studies have evaluated maxillary sinus morphology, limited evidence is available regarding its association with different craniofacial growth patterns. The present study was undertaken to compare maxillary sinus volume among individuals with horizontal, average, and vertical growth patterns using cone-beam computed tomography (CBCT). **Materials and Methods:** This retrospective observational study included 45 CBCT scans of individuals aged 18–30 years with fully developed maxillary sinuses. Based on the Frankfurt mandibular plane angle (FMA), participants were equally allocated into horizontal ($\leq 21^\circ$), average (22° – 28°), and vertical ($\geq 29^\circ$) growth pattern groups. Maxillary sinus volumes were measured using Dolphin 3D software following standardized three-dimensional segmentation. Data were analysed using the Independent Samples Median Test with post-hoc pairwise comparisons, and statistical significance was considered at $p < 0.001$. **Results:** A significant increase in maxillary sinus volume was observed from the horizontal to the vertical growth pattern groups ($p < 0.001$). The horizontal group demonstrated the lowest mean sinus volume ($9,822 \pm 1300.35 \text{ mm}^3$), the average group showed intermediate values ($13,662.73 \pm 1390.69 \text{ mm}^3$), while the vertical growth pattern exhibited the highest mean volume ($18,072.07 \pm 2935.58 \text{ mm}^3$). Pairwise comparisons confirmed significant differences between all three groups. **Conclusion:** Maxillary sinus volume varies significantly with craniofacial growth pattern, with individuals exhibiting a vertical growth pattern demonstrating the largest sinus volumes. These findings highlight the value of CBCT-based three-dimensional assessment in improving orthodontic diagnosis, treatment planning, and clinical decision-making involving the posterior maxilla.

Keywords: Maxillary sinus volume, cone-beam computed tomography, craniofacial growth pattern, Frankfurt mandibular plane angle, orthodontics

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INTRODUCTION

The maxillary sinus is the largest of the paranasal sinuses and plays an important role in craniofacial development, respiration, resonance, and structural adaptation of the midface. It develops during embryogenesis and continues to enlarge through pneumatization until early adulthood. Variations in its

morphology are influenced by age, sex, genetic factors, and craniofacial growth characteristics. Because of its close relationship with the maxilla and posterior teeth, understanding maxillary sinus morphology is important in orthodontics and dentofacial orthopaedics.¹

The maxillary sinus develops concurrently with the surrounding facial skeleton, and its dimensions are influenced by maxillary growth and remodeling. Basdra et al. reported that sinus growth is closely associated with craniofacial development, suggesting that skeletal morphology and sinus anatomy are interrelated.² Previous studies have also demonstrated considerable individual variation in sinus pneumatization, influenced by both developmental and environmental factors.³

Age-related alterations in maxillary sinus morphology have been documented by several investigators. Jun et al. demonstrated progressive changes in sinus aeration with advancing age,⁴ while Arijji et al. reported significant age-related differences in maxillary sinus volume.⁵ In addition, sex-related differences have been observed, indicating that biological factors also contribute to variations in sinus morphology.⁶

The anatomical relationship between the maxillary sinus and posterior teeth has important clinical implications during orthodontic treatment. The proximity of the sinus floor to posterior tooth roots may influence orthodontic tooth movement, particularly during molar intrusion and space closure. Sharan and Madjar emphasized the importance of evaluating sinus anatomy before initiating orthodontic treatment,⁷ whereas Park et al. demonstrated that controlled tooth movement through the maxillary sinus is feasible with appropriate biomechanics.⁸

The introduction of cone-beam computed tomography (CBCT) has enabled accurate three-dimensional evaluation of maxillary sinus morphology. Compared with conventional radiography, CBCT provides precise volumetric assessment with minimal distortion. Recent CBCT studies have demonstrated significant differences in maxillary sinus volume among various craniofacial growth patterns.^{9, 10}

Individuals with different vertical skeletal patterns exhibit variations in facial morphology that may influence sinus development. Previous CBCT studies have consistently reported larger maxillary sinus volumes in individuals with vertical facial patterns than in those with horizontal growth patterns.^{11–13} Furthermore, orthognathic surgical procedures have also been shown to influence maxillary sinus dimensions, highlighting the close relationship between skeletal morphology and sinus anatomy.^{14, 15}

Although previous studies have evaluated maxillary sinus dimensions in relation to age, sex, and skeletal characteristics, evidence regarding the influence of craniofacial growth pattern on maxillary sinus volume remains limited. Therefore, the present study was undertaken to evaluate and compare maxillary sinus volume among individuals with horizontal, average, and vertical craniofacial growth patterns using CBCT.

MATERIALS AND METHODS

Study Design

This retrospective observational study was conducted using cone-beam computed tomography (CBCT) records obtained from patients who had undergone CBCT imaging for diagnostic purposes at Amrita School of Dentistry. The study utilized previously acquired radiographic records, and all patient information was anonymized before analysis in accordance with institutional guidelines.

Sample Selection

The sample size was determined based on previously published studies evaluating maxillary sinus volume in relation to different craniofacial growth patterns. A total of 45 CBCT scans fulfilling the predefined eligibility criteria were included in the study. Individuals aged between 18 and 30 years with fully developed maxillary sinuses, complete craniofacial CBCT records, and reconstructed lateral cephalometric images suitable for skeletal assessment were considered eligible. Only CBCT scans with adequate image quality and minimal artefacts were included to ensure accurate volumetric analysis. Patients with a history of

maxillofacial trauma, orthognathic surgery, congenital craniofacial anomalies, sinus pathology, mucosal thickening, cysts, tumours, or incomplete radiographic records were excluded from the study.

CBCT Image Acquisition

The CBCT datasets were exported in Digital Imaging and Communications in Medicine (DICOM) format and imported into Dolphin 3D software (Dolphin Imaging and Management Solutions, USA) for volumetric assessment. All images were analysed under standardized viewing conditions after proper orientation of the reconstructed three-dimensional craniofacial models to ensure uniformity during image evaluation.

Classification of Craniofacial Growth Pattern

Reconstructed lateral cephalometric images derived from the CBCT datasets were used to classify participants according to their craniofacial growth pattern (Fig. 1). The Frankfurt mandibular plane angle (FMA), measured between the Frankfurt horizontal plane and the mandibular plane, was used as the reference parameter for skeletal classification. Based on the measured FMA values, participants were categorized into three groups: Group I comprised individuals with a horizontal growth pattern ($FMA \leq 21^\circ$), Group II included those with an average growth pattern ($FMA 22^\circ\text{--}28^\circ$), and Group III consisted of individuals with a vertical growth pattern ($FMA \geq 29^\circ$). All cephalometric measurements and classifications were performed by a single examiner to minimize inter-observer variability.

Three-Dimensional Evaluation of Maxillary Sinus Volume

Following image orientation, the maxillary sinus was segmented using Dolphin 3D software. The boundaries of the sinus were identified in the axial, sagittal, and coronal planes, and the sinus cavity was manually delineated from the surrounding anatomical structures. The software subsequently generated a three-dimensional reconstruction and automatically calculated the sinus volume. Measurements were obtained separately for the right and left maxillary sinuses (Figs. 2 and 3), and the average of the two measurements was considered the final maxillary sinus volume for each participant.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics (IBM Corp., Armonk, NY, USA). Descriptive statistics were expressed as mean, standard deviation, median, and interquartile range. Data normality was assessed using the Shapiro–Wilk test. Since the data did not satisfy the assumptions of normality, comparisons among the three craniofacial growth pattern groups were performed using the Independent Samples Median Test, followed by post-hoc pairwise comparisons. A p-value of <0.001 was considered statistically significant.

Outcome Measure

The primary outcome measure of the study was the comparison of mean maxillary sinus volume among individuals with horizontal, average, and vertical craniofacial growth patterns.

RESULTS

A total of 45 CBCT records meeting the eligibility criteria were included in the study. Based on the Frankfurt mandibular plane angle (FMA), the study participants were equally classified into three groups: horizontal growth pattern ($n = 15$), average growth pattern ($n = 15$), and vertical growth pattern ($n = 15$).

The descriptive statistics of maxillary sinus volume among the three craniofacial growth patterns are presented in Table 1. Individuals with a horizontal growth pattern demonstrated the lowest mean maxillary sinus volume ($9,822 \pm 1300.35 \text{ mm}^3$), whereas those with an average growth pattern exhibited an intermediate mean volume ($13,662.73 \pm 1390.69 \text{ mm}^3$). The highest mean maxillary sinus volume was observed in the vertical

growth pattern group ($18,072.07 \pm 2935.58 \text{ mm}^3$). Similarly, the median sinus volume showed a progressive increase from the horizontal ($10,217 \text{ mm}^3$) to the average ($14,202 \text{ mm}^3$) and vertical ($17,389 \text{ mm}^3$) growth pattern groups. The Independent Samples Median Test demonstrated a statistically significant difference in maxillary sinus volume among the three groups ($p < 0.001$) (Table 1).

The distribution of maxillary sinus volume across the three craniofacial growth patterns is illustrated in Figure 4. The box-and-whisker plot demonstrated a gradual increase in sinus volume from the horizontal to the vertical growth pattern groups. In addition, the vertical growth pattern group showed a wider interquartile range and greater dispersion of values, indicating increased variability in sinus volume compared with the horizontal and average growth pattern groups (Fig. 4).

Since the data did not satisfy the assumptions of normal distribution, the Independent Samples Median Test was performed to compare maxillary sinus volume among the three craniofacial growth pattern groups. The analysis revealed a statistically significant difference in median sinus volume across the study groups ($p < 0.001$), indicating that maxillary sinus volume varied significantly according to craniofacial growth pattern (Table 1).

Post-hoc pairwise comparisons further demonstrated statistically significant differences between each pair of growth patterns. Significant differences were observed between the horizontal and average growth pattern groups, the horizontal and vertical growth pattern groups, and the average and vertical growth pattern groups, with all adjusted p -values remaining below 0.001.

Overall, the findings demonstrated a progressive increase in maxillary sinus volume with increasing vertical craniofacial growth tendency. Individuals with a vertical growth pattern exhibited significantly greater maxillary sinus volumes than those with average and horizontal growth patterns, confirming a strong association between craniofacial growth pattern and maxillary sinus morphology (Table 1, Fig. 4).

DISCUSSION

The present retrospective CBCT study evaluated the association between maxillary sinus volume and different craniofacial growth patterns. The findings demonstrated a statistically significant increase in maxillary sinus volume from the horizontal to the vertical growth pattern groups ($p < 0.001$). Participants with a vertical growth pattern exhibited the highest mean maxillary sinus volume ($18,072.07 \pm 2935.58 \text{ mm}^3$), whereas those with a horizontal growth pattern demonstrated the lowest mean volume ($9,822 \pm 1300.35 \text{ mm}^3$). Individuals with an average growth pattern showed intermediate values, indicating a progressive increase in sinus volume with increasing vertical facial divergence (Table 1, Fig. 4).

The maxillary sinus develops in close association with the surrounding craniofacial skeleton and undergoes continuous remodeling during growth and maturation. As pneumatization progresses, the sinus expands within the maxillary bone, and its final dimensions are influenced by skeletal morphology. Basdra et al.² reported that the maxillary sinus contributes significantly to facial development and adapts to changes occurring within the craniofacial complex. The findings of the present study further support this concept by demonstrating significant differences in sinus volume among the three craniofacial growth patterns.

The greater maxillary sinus volumes observed in individuals with a vertical growth pattern may be explained by the anatomical characteristics of hyperdivergent facial morphology. Increased lower anterior facial height, greater vertical maxillary development, and clockwise rotation of the mandible provide a larger skeletal framework that facilitates sinus pneumatization. Conversely, individuals with horizontal growth patterns generally exhibit reduced vertical facial dimensions and a comparatively compact maxillary architecture, thereby limiting sinus expansion.

These anatomical differences may account for the progressive increase in sinus volume observed across the three study groups.

The present findings are consistent with those reported in previous CBCT-based investigations. Okşayan et al.¹¹ demonstrated significantly larger maxillary sinus dimensions in individuals with vertical facial patterns than in those with horizontal growth patterns. Similarly, Shrestha et al.⁹ reported significant variations in maxillary sinus volume among different craniofacial growth patterns, while Kumar et al.¹⁰ observed that sinus dimensions were influenced by craniofacial skeletal morphology. More recently, Dinç and İçöz¹² reported significantly greater sinus volumes in hyperdivergent individuals compared with hypodivergent subjects. Likewise, Bagchi et al.¹³ demonstrated a positive association between vertical facial pattern and maxillary sinus volume in skeletal Class I adults. Collectively, these findings corroborate the results of the present study and reinforce the influence of craniofacial growth pattern on maxillary sinus morphology.

Age is another important factor known to influence maxillary sinus morphology. Previous studies have shown that sinus pneumatization continues throughout adolescence and early adulthood before reaching relative stability. Jun et al.⁴ demonstrated progressive changes in sinus aeration with advancing age, whereas Arij et al.⁵ reported age-related variations in maxillary sinus volume using computed tomography. To minimize the confounding effect of age, the present study included only young adults with fully developed maxillary sinuses.

The anatomical relationship between the maxillary sinus and posterior maxillary teeth has considerable clinical relevance in orthodontics. As sinus volume increases, the sinus floor may extend closer to the roots of posterior teeth, potentially influencing orthodontic tooth movement during molar intrusion, distalization, en-masse retraction, and space closure. Sharan and Madjar⁷ demonstrated a significant relationship between the morphology of the maxillary sinus floor and posterior tooth roots, emphasizing the importance of careful radiographic evaluation before orthodontic treatment. Similarly, Park et al.⁸ reported that controlled orthodontic tooth movement through the maxillary sinus is feasible when appropriate biomechanical principles are followed. Therefore, three-dimensional CBCT assessment should be considered an integral part of orthodontic diagnosis and treatment planning, particularly in patients exhibiting vertical craniofacial growth patterns.

The findings of the present study also have important implications beyond orthodontics. Variations in maxillary sinus volume may influence procedures such as implant placement, sinus floor elevation, and orthognathic surgery by altering the available bone volume and anatomical relationships within the posterior maxilla. Panou et al.¹⁴ demonstrated that orthognathic surgery can produce measurable changes in maxillary sinus dimensions, highlighting the close relationship between skeletal repositioning and sinus morphology. Consequently, accurate preoperative CBCT evaluation may facilitate better surgical planning and reduce the risk of intraoperative complications.

One of the major strengths of the present study is the use of CBCT for three-dimensional volumetric evaluation of the maxillary sinus. Compared with conventional two-dimensional radiographic techniques, CBCT provides accurate visualization with minimal distortion and without anatomical superimposition, enabling reliable assessment of sinus morphology.¹ Furthermore, standardized image orientation, volumetric reconstruction using Dolphin 3D software, and objective classification of craniofacial growth patterns using the Frankfurt mandibular plane angle enhanced the reliability and reproducibility of the measurements.^{9,10}

Despite these strengths, certain limitations should be acknowledged. The retrospective design may have introduced selection bias because only previously available CBCT records

were included. In addition, the relatively small sample size may limit the generalizability of the findings. Other variables that may influence maxillary sinus morphology, including sex, ethnicity, dental status, and skeletal malocclusion, were not evaluated separately. Future multicentre studies with larger sample sizes and multivariable analyses are required to further clarify the influence of these factors on maxillary sinus volume.

Future longitudinal investigations evaluating changes in maxillary sinus volume during craniofacial growth and following orthodontic treatment would provide additional insight into sinus development. Further studies assessing the combined influence of vertical and sagittal skeletal relationships, sex-related differences, and the relationship between sinus volume and posterior tooth root proximity may enhance the clinical relevance of these findings.

CONCLUSION

Within the limitations of this retrospective CBCT study, maxillary sinus volume differed significantly among individuals with different craniofacial growth patterns. Participants with a vertical growth pattern demonstrated the largest maxillary sinus volumes, whereas those with a horizontal growth pattern exhibited the smallest volumes (Table 1, Fig. 4). These findings indicate that maxillary sinus morphology is closely associated with craniofacial skeletal growth and should be considered during orthodontic diagnosis and treatment planning.

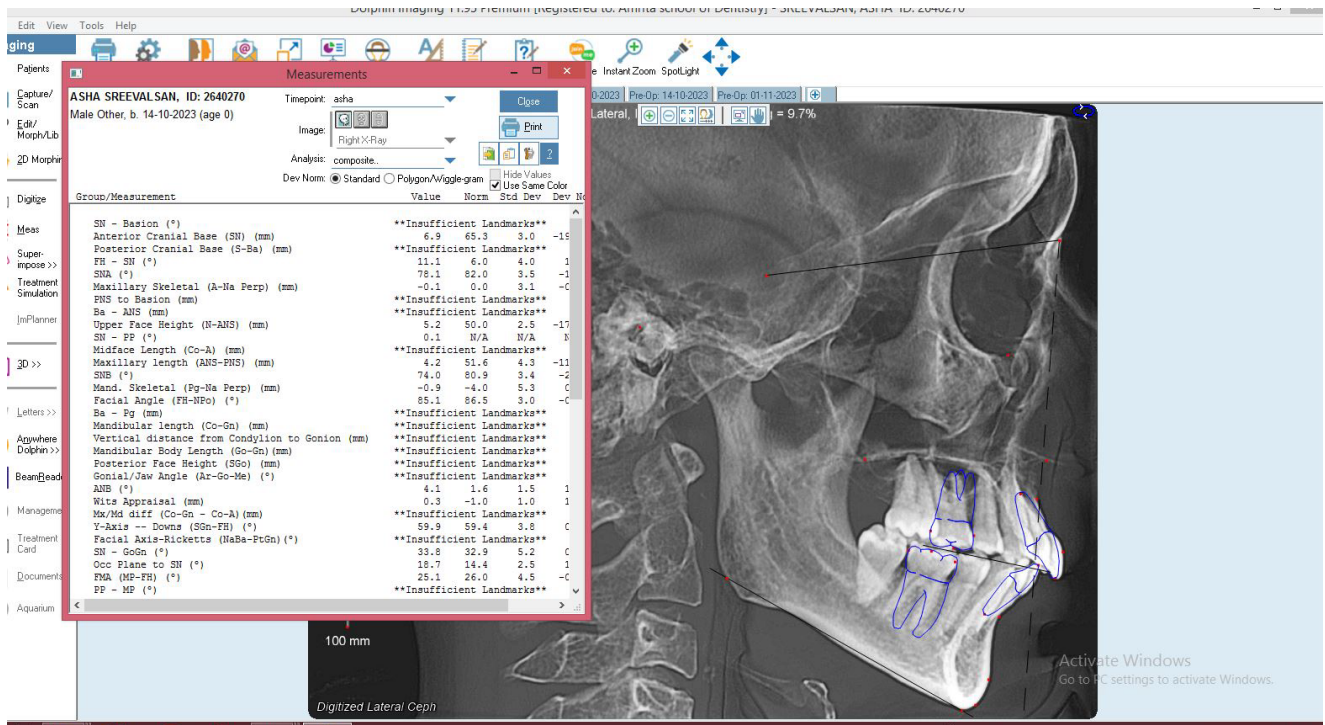
The use of three-dimensional CBCT imaging enabled accurate volumetric assessment of the maxillary sinus, providing clinically relevant information that may assist in treatment planning involving the posterior maxilla. A comprehensive understanding of these anatomical variations may contribute to improved biomechanical planning, safer orthodontic tooth movement, and better clinical outcomes. Further prospective studies with larger and more diverse populations are recommended to validate these findings and to investigate the influence of additional skeletal and demographic factors on maxillary sinus morphology.

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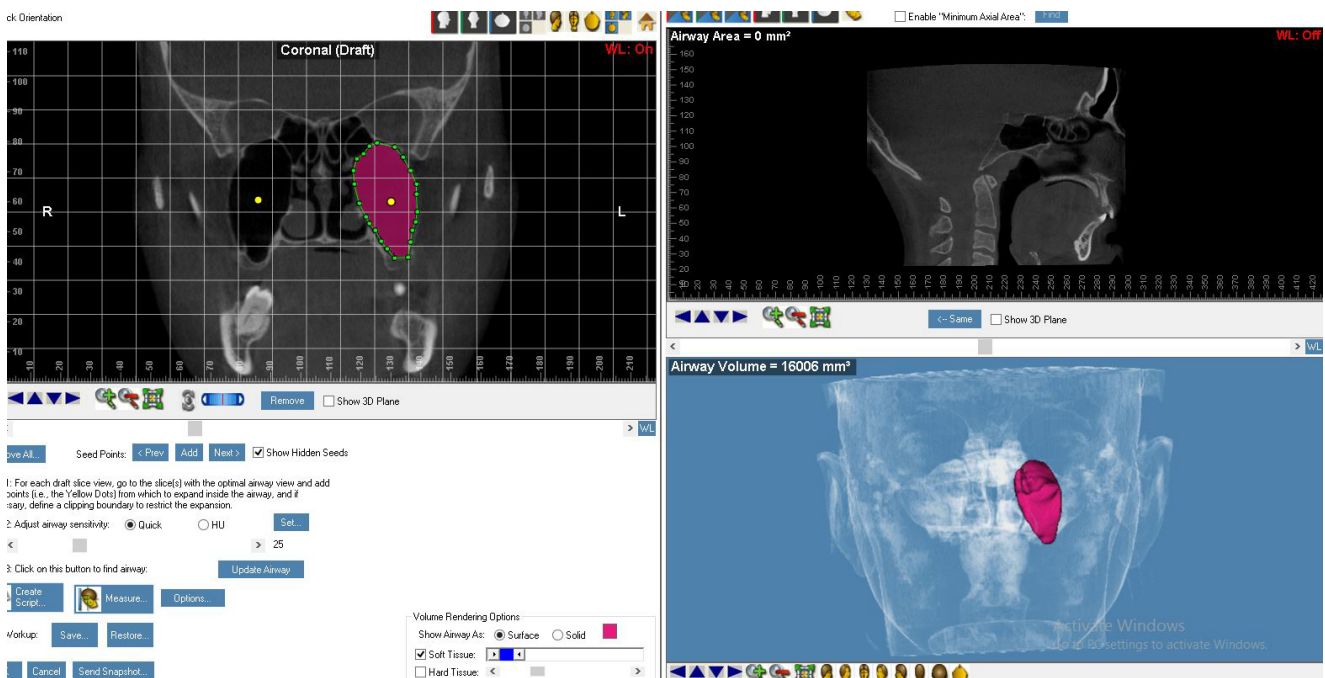
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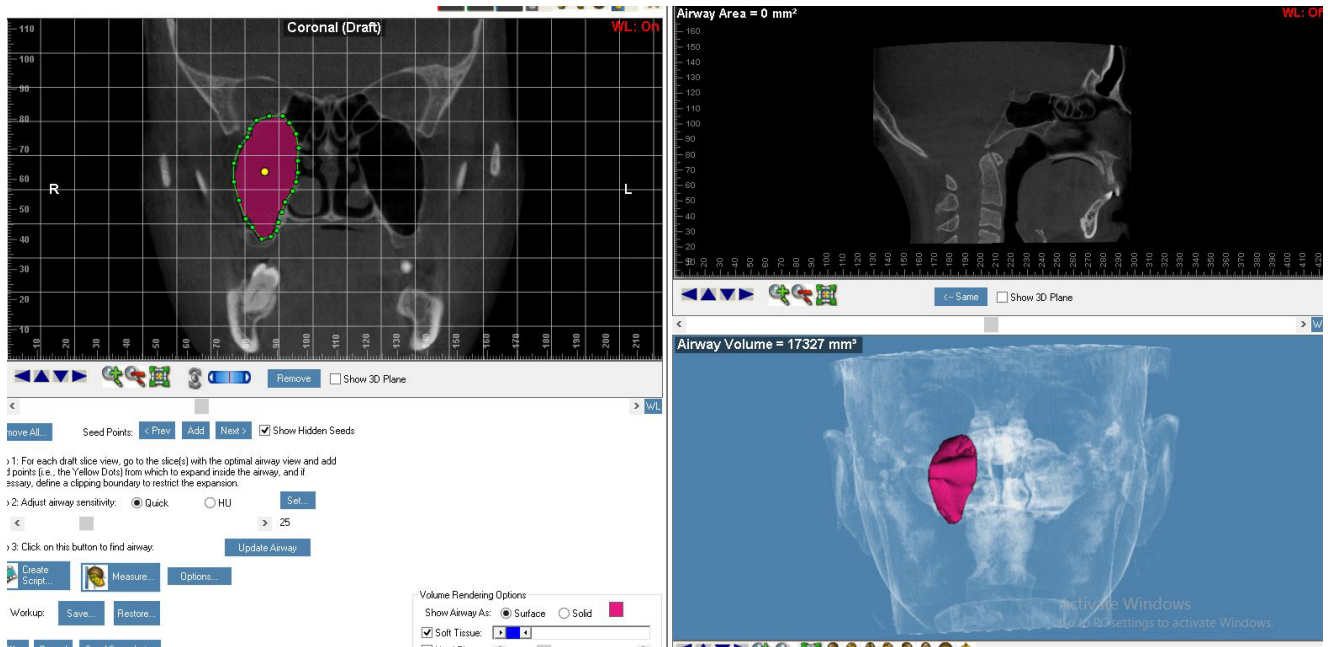
Figures



Determination of craniofacial growth pattern using reconstructed lateral cephalometric analysis.

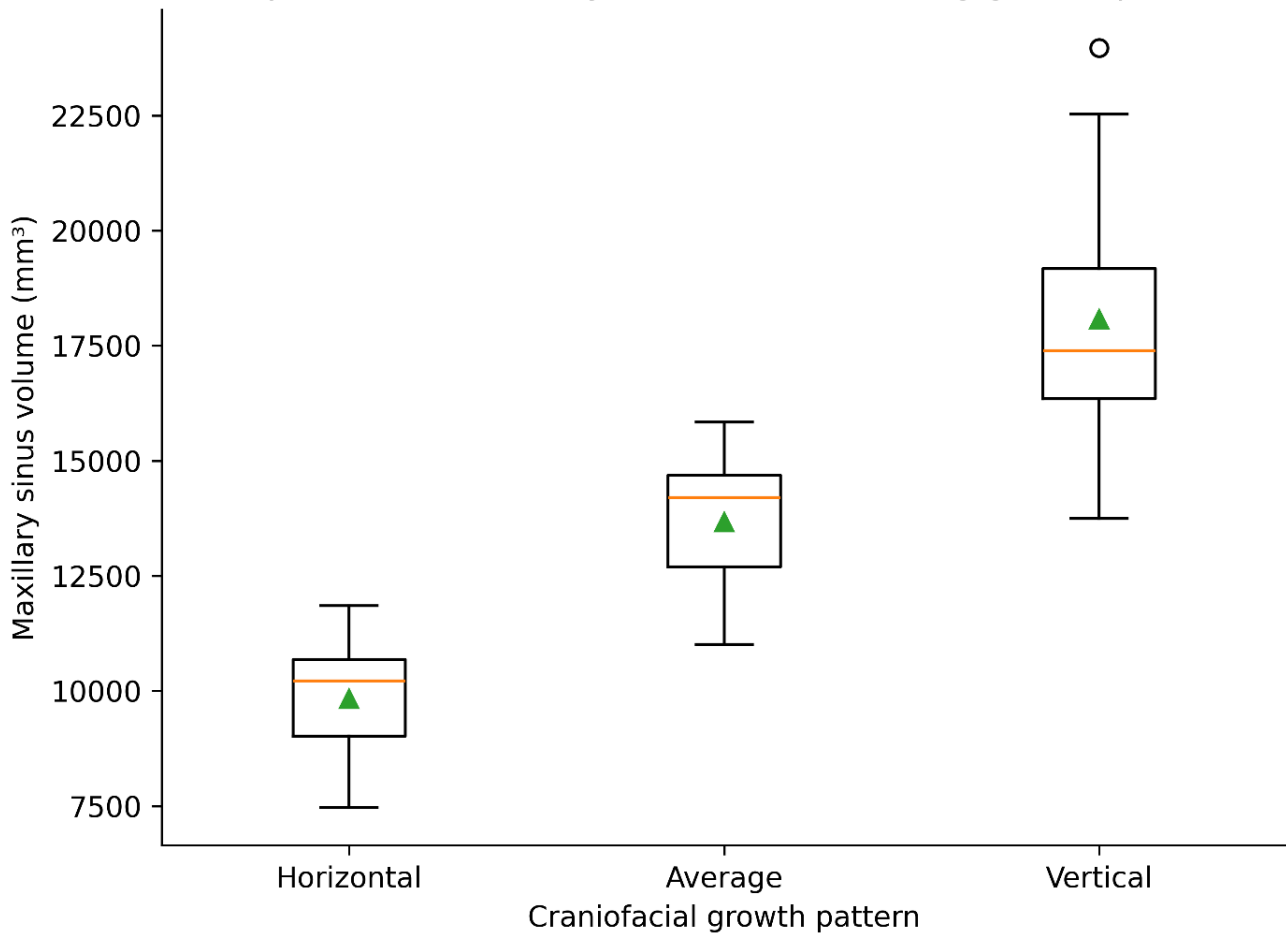


Three-dimensional segmentation and volumetric assessment of the left maxillary sinus using Dolphin 3D software.



Three-dimensional segmentation and volumetric assessment of the right maxillary sinus using Dolphin 3D software.

Comparison of maxillary sinus volume among growth patterns



Distribution of maxillary sinus volume among horizontal, average, and vertical craniofacial growth patterns using a box-and-whisker plot.

Comparison of Maxillary Sinus Volume among Different Craniofacial Growth Patterns.

CRANIOFACIAL GROWTH PATTERN	HORIZONTAL (n=15)	AVERAGE (n=15)	VERTICAL (n=15)	
MEAN	9822	13662.73	18072.07	
STANDARD DEVIATION	1300.353	1390.698	2935.589	
MEDIAN	10217	14202	17389	
PERCENTILE	Q1(25th percentile)	8880	12640.00	16182.00
	50th percentile	10217.60	14202.00	17389.00
	Q3(75th percentile)	10773.00	14777.00	19676.00
p-VALUE	<0.001	<0.001	<0.001	