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Research Paper

Evaluation of Maxillary Sinus in Health and Disease Using Cone-Beam Computed Tomography: A Comparative Retrospective Study

Dr. Somya Jaiswal[1], Dr. Priya Singh[2], Dr. Deepak U[3], Dr. Puja Rai[4]
Dr. Saurabh Srivastava[5]
[1]*Junior Resident Department of Oral Medicine & Radiology, BBDCODS Lucknow India*
[2]*Professor Department of Oral Medicine & Radiology, BBDCODS Lucknow India*
[3]*Professor and Head Department of Oral Medicine & Radiology, BBDCODS Lucknow India*
[4]*Reader Department of Oral Medicine & Radiology, BBDCODS Lucknow India*
[5]*Reader Department of Oral Medicine & Radiology, BBDCODS Lucknow India*

Abstract:
Background: *The maxillary sinus plays a critical role in dental and maxillofacial procedures due to its close anatomical relationship with posterior maxillary teeth. Accurate evaluation of sinus anatomy and pathology is essential for diagnosis and treatment planning. Cone-beam computed tomography (CBCT) offers three-dimensional assessment with high spatial resolution and is increasingly used for detailed sinus evaluation.*
Aim: *To evaluate and compare maxillary sinus morphology and pathology in healthy and diseased sinuses using CBCT and to identify predictors of maxillary sinus pathology.*
Materials and Methods: *A retrospective cross-sectional study was conducted using CBCT scans of 60 individuals aged 18–70 years. The sample was divided into a control group (healthy sinuses; n = 30) and a pathological group (sinus pathology; n = 30). Maxillary sinus volume and linear dimensions (length, width, and height) were measured. Pathological findings, severity of mucosal thickening, and posterior tooth root–sinus floor relationships were assessed. Statistical analysis included descriptive statistics, group comparisons, correlation analysis, and multivariate logistic regression, with $p < 0.05$ considered statistically significant.*
Results: *The pathological group demonstrated significantly reduced maxillary sinus volume, length, and height compared with controls ($p = 0.001$), while sinus width did not differ significantly ($p = 0.844$). Mucosal thickening was the most prevalent pathological finding. No significant correlation was observed between age and sinus morphometric parameters in either group. Logistic regression analysis identified reduced sinus volume, length, and height as independent predictors of maxillary sinus pathology, whereas age, gender, and posterior tooth root proximity were not significant predictors.*
Conclusion: *Maxillary sinus pathology is associated with significant morphometric reduction, particularly in volume and vertical and anteroposterior dimensions. CBCT provides valuable quantitative and qualitative information and should be routinely used for comprehensive evaluation of the maxillary sinus in clinical practice.*

Keywords: *Cone-Beam Computed Tomography; Maxillary Sinus; Sinusitis; Morphometry; Dental Radiography; Odontogenic Diseases*

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I. Introduction

The maxillary sinus (MS) is the largest of the paranasal sinuses and forms an essential anatomic interface between the oral cavity and the sinonasal complex. Its close proximity to the posterior maxillary teeth, alveolar process, and osteomeatal unit makes it clinically important across dentistry, oral and maxillofacial surgery, endodontics, periodontics, and otorhinolaryngology [1]. Even subtle sinus changes can influence outcomes of common interventions such as extractions, endodontic therapy, implant placement, sinus floor elevation, and management of oroantral communications [2]. Conversely, dental disease is increasingly recognized as a major contributor to unilateral or refractory maxillary sinusitis (MSitis), with odontogenic maxillary sinusitis (OMS) representing a distinct entity that differs from rhinogenic sinusitis in etiology, microbiology, and treatment response. Contemporary reviews and international consensus guidance emphasize that accurate identification of a dental source is central to effective care, and that imaging plays a decisive role in confirming OMS and guiding combined dental–ENT management. [3,4]

Radiologic evaluation of the MS has therefore become a core component of comprehensive assessment in both health (baseline anatomy and variations) and disease (mucosal and ostial pathology, odontogenic sources, and complication risk). However, traditional 2-dimensional (2D) imaging modalities such as panoramic radiography and periapical radiographs have inherent limitations, including superimposition, geometric distortion, and reduced sensitivity for sinus mucosal abnormalities, ostial obstruction, or subtle bony changes [5]. In contrast, cone-beam computed tomography (CBCT) provides high-resolution, three-dimensional (3D) visualization of the maxillofacial complex with multiplanar reconstruction, enabling superior depiction of sinus walls, floor contour, septa, ostial anatomy, sinus pneumatization patterns, and tooth–sinus spatial relationships. These capabilities are clinically meaningful because many relevant MS conditions—mucosal thickening, polypoidal change, retention cysts, partial opacification, and ostial narrowing—may be missed or underestimated on 2D imaging, particularly when pathology is localized to the sinus floor or medial wall. [6]

CBCT-based assessments have also highlighted that "normal" MS anatomy is highly variable and population-dependent. A systematic review and meta-analysis evaluating maxillary region variations reported frequent anatomic variants relevant to the MS and osteomeatal complex, including septa, accessory ostia, nasal septal deviation, concha bullosa/Haller cells, and mucosal thickening—features that may modify ventilation and drainage and may increase the technical difficulty and complication risk of sinonasal and dentoalveolar procedures. [7] In addition, large CBCT series demonstrate that incidental MS findings are common in routine dental scans. For example, a large retrospective CBCT study of 1000 maxillary sinuses reported that nearly half of sinuses demonstrated some pathologic change, with mucous retention cysts and polypoidal mucosal thickening among the most frequent findings; importantly, associations were observed between sinus pathology and factors such as ostial obstruction and sinus pneumatization, underscoring the interdependence of anatomy and disease expression. [6] Such observations reinforce the need for structured CBCT evaluation protocols and clear criteria to distinguish normal variants from clinically relevant disease.

Beyond descriptive anatomy, CBCT is increasingly used to quantify MS morphology (e.g., linear dimensions and volumetry), which may vary with age, sex, craniofacial pattern, tooth loss, and nasal septal deviation. Volumetric CBCT studies report measurable differences in sinus volume related to demographic and anatomic variables, supporting the concept that "baseline" MS morphology is not uniform and that population-specific reference data can improve interpretation. [8] Similarly, CBCT-based population analyses have documented that MS dimensions and certain abnormalities may be more prevalent in specific age/sex strata, reinforcing the importance of contextual interpretation rather than applying a single threshold-based approach to all patients. [9]

A major contemporary driver for CBCT-based sinus evaluation is the rising recognition of OMS. OMS typically results from periapical disease, periodontal infection, complications of extractions, implant-related pathology, or iatrogenic disruption of the Schneiderian membrane, and may account for a substantial proportion of unilateral maxillary sinusitis. Modern multidisciplinary consensus statements recommend that OMS diagnosis should integrate clinical assessment with imaging evidence of sinus disease contiguous with a dental source, and they highlight the importance of collaboration between dental clinicians and ENT specialists to reduce chronicity and recurrence. [2,3] CBCT is particularly suited to OMS evaluation because it can simultaneously depict maxillary posterior teeth (apical lesions, periodontal bone loss, endodontic complications) and sinus findings (floor mucosal thickening, polypoidal changes, fluid levels/opacification), thereby supporting source attribution and procedural planning. [1–3]

Despite its advantages, CBCT interpretation requires appropriate justification and standardization. Professional guidance underscores that CBCT should be used when the expected diagnostic or treatment-planning benefit outweighs the radiation exposure, and that images must be interpreted systematically within the entire field of view (including sinonasal structures when captured). Updated position statements and clinical guidance continue to refine indications and reporting expectations for CBCT use in dentomaxillofacial practice. [10] Within this context, research focusing on "evaluation of the maxillary sinus in health and disease" using CBCT is clinically relevant for several reasons: (i) establishing normative anatomic patterns and common variants in the target population; (ii) defining the prevalence and spectrum of sinus abnormalities detectable on CBCT; (iii) examining associations between dental variables and sinus pathology to strengthen OMS recognition; and (iv) supporting safer planning of procedures involving the posterior maxilla and sinus (e.g., implants and sinus augmentation), where unrecognized pathology or complex septal anatomy may increase complications.

Accordingly, the present study uses CBCT to systematically characterize MS anatomy and variations in health and to evaluate the prevalence and patterns of MS disease, with an emphasis on findings that are directly relevant to dental diagnosis, procedural planning, and multidisciplinary management of sinonasal–odontogenic conditions.

II. Materials and Methods

Study Design

This study was designed as a retrospective cross-sectional observational study aimed at evaluating and comparing the anatomical and pathological characteristics of the maxillary sinus in healthy individuals and in patients with sinus-related disease using cone-beam computed tomography (CBCT). The retrospective design enabled analysis of previously acquired CBCT scans, thereby avoiding additional radiation exposure to patients. The cross-sectional nature of the study facilitated comparison between healthy and pathological groups at a single point in time, providing a comprehensive overview of maxillary sinus status across different individuals.

Study Setting

The study was conducted at X-Vision CBCT Center, Lucknow, Uttar Pradesh, India, a specialized diagnostic imaging facility equipped with advanced CBCT technology. All scans were acquired using the Carestream CS 9600 CBCT unit (Carestream Dental, USA). Imaging parameters included a tube voltage range of 90–120 kVp, tube current of 5–10 mA, voxel size ranging from 0.3 to 0.5 mm, and an exposure time of approximately 7.9 seconds. The imaging center caters to a diverse patient population from multiple geographic regions, ensuring an adequately representative sample for retrospective analysis.

Study Duration

The study was conducted over a period of 18 months, beginning in July 2023 and concluding in January 2025. This duration encompassed retrieval of CBCT scans from digital archives, screening for eligibility, image evaluation, measurement procedures, and statistical analysis of the collected data.

Study Population

The study population consisted of adult patients of either sex aged between 18 and 70 years who had undergone CBCT scanning for evaluation of the maxillary sinus region. Only CBCT images that were clear, diagnostically adequate, and free from artifacts affecting the maxillary sinus were included. Patients with developmental anomalies or congenital malformations involving the maxilla or paranasal sinuses were excluded. CBCT scans showing motion artifacts or metallic interference in the maxillary sinus region were also excluded. Additionally, individuals with a history of previous maxillary sinus surgery or dental implant placement that could alter normal sinus anatomy were not considered for inclusion.

Sampling Method and Sample Size

A purposive sampling method was adopted to select CBCT scans that fulfilled the predefined inclusion and exclusion criteria. This approach ensured inclusion of images that were relevant to the study objectives and suitable for accurate anatomical and pathological assessment. A total of 60 CBCT scans were included in the study. Of these, 30 scans were obtained from individuals without maxillary sinus pathology and constituted the control group, while the remaining 30 scans were from individuals diagnosed with maxillary sinus pathology and formed the pathological group. The sample size was determined based on the availability of eligible scans in the center's database and was considered adequate to allow meaningful comparative statistical analysis between the two groups.

Group Allocation

The study sample was divided into two groups. Group I comprised CBCT scans of individuals with healthy maxillary sinuses and served as the control group, providing baseline data on normal anatomical variations. Group II included CBCT scans of individuals with radiographic evidence of maxillary sinus pathology, such as mucosal thickening, sinusitis, polyps, or retention cysts. The two groups were matched for age and gender distribution as far as possible to minimize the influence of demographic confounding factors.

Study Parameters

The parameters evaluated in this study included maxillary sinus dimensions, sinus volume, and pathological findings. Linear dimensions assessed included sinus height, width, and length. Volumetric analysis of the maxillary sinus was performed to compare sinus volume between healthy and pathological groups. Pathological assessment focused on identifying the presence, extent, and type of sinus pathology, including mucosal thickening, polyps, cysts, and sinus opacification. In addition, the proximity of posterior maxillary tooth roots to the floor of the maxillary sinus was evaluated to assess potential odontogenic influences on sinus health.

CBCT Image Retrieval and Analysis

CBCT images were retrieved from the digital archives of the imaging center. All images were analyzed using CS 3D Suite software (Carestream Dental, USA). Evaluation was performed in axial, coronal, and sagittal planes. Anatomical landmarks were identified, and measurements were carried out using the software's built-in measurement tools. Each image was carefully reviewed to ensure accuracy and consistency in identification of anatomical structures and pathological features.

Measurement of Maxillary Sinus Dimensions

Maxillary sinus height was measured as the maximum vertical distance from the lowest point of the sinus floor to the highest point of the sinus roof on sagittal reconstructed images. Maxillary sinus width was measured as the maximum mediolateral distance perpendicular to the midline on coronal reconstructed images. Maxillary sinus length was measured as the maximum anteroposterior distance from the most anterior to the most posterior point of the sinus on coronal sections.

CBCT-Based Volumetric Assessment of the Maxillary Sinus

Maxillary sinus volume was estimated using a **CBCT-based geometric approximation method** derived from linear sinus dimensions. For each sinus, volume was calculated using the formula:

$$\text{Sinus Volume} = \text{Length} \times \text{Width} \times \text{Height} \times 0.52$$

This coefficient approximates the sinus cavity to an ellipsoid shape and has been previously applied in CBCT-based morphometric studies where segmentation-based volumetry is not feasible. Volumetric values were expressed in cubic centimeters (cm^3). The same measurement protocol was applied uniformly across both study groups to ensure comparability.

Pathological Assessment

The presence and characteristics of maxillary sinus pathology were documented for each scan. Mucosal thickening was assessed based on thickness measurements, while sinus polyps and cysts were recorded with respect to their size and anatomical location. Partial or complete sinus opacification was also noted where present.

Proximity Analysis of Posterior Teeth Roots

The distance between the apices of posterior maxillary teeth and the floor of the maxillary sinus was measured on CBCT images to evaluate the proximity of tooth roots to the sinus floor. This analysis was performed to assess potential odontogenic influences on maxillary sinus health.

Data Recording and Preparation

All measurements and observations were systematically recorded in a structured proforma to ensure uniform data collection. The collected data were coded and entered into a database for subsequent statistical analysis.

III. Statistical Analysis

Statistical analysis was performed using **SPSS software (version 26.0)**. Continuous variables were summarized as mean and standard deviation, while categorical variables were expressed as frequencies and percentages. Normality of data distribution was assessed prior to inferential testing.

Comparisons between control and pathological groups were performed using the **independent t-test** for normally distributed variables and the **Mann–Whitney U test** for non-normally distributed variables. Associations between age and sinus morphometric parameters were evaluated using **Pearson's or Spearman's correlation coefficients**, as appropriate.

A **multivariate logistic regression model** was constructed to assess independent associations between maxillary sinus morphometric parameters and the presence of radiographic sinus pathology. Odds ratios (ORs) with 95% confidence intervals (CIs) were calculated. A p-value of <0.05 was considered statistically significant.

IV. Results

Table 1 summarizes the baseline demographic characteristics of the study participants. Both the control and pathological groups were perfectly matched for gender, with males and females each accounting for 50% (15/30) of participants in both groups, thereby eliminating gender as a confounding variable. The mean age of participants was higher in the pathological group (43.83 years) compared with the control group (38.53 years), with an overall mean age of 41.19 years for the total sample. Although the age range was identical in both groups

(18–70 years), age-wise distribution revealed a greater proportion of older individuals in the pathological group, particularly in the 61–70-year category (23.3% vs. 10.0% in controls). Conversely, younger age groups (18–30 years) were more represented in the control group (30.0%) than in the pathological group (20.0%).

TABLE 1. Baseline Demographic Characteristics of Study Participants

Variable	Control Group (n = 30)	Pathological Group (n = 30)	Total (n = 60)
Gender			
Male	15 (50%)	15 (50%)	30 (50%)
Female	15 (50%)	15 (50%)	30 (50%)
Age (years)			
Mean ± SD	38.53 ± 12.4	43.83 ± 13.8	41.19 ± 13.2
Range	18–70	18–70	18–70
Age distribution			
18–30 years	9 (30.0%)	6 (20.0%)	15 (25.0%)
31–40 years	11 (36.7%)	9 (30.0%)	20 (33.3%)
41–50 years	3 (10.0%)	5 (16.7%)	8 (13.3%)
51–60 years	4 (13.3%)	3 (10.0%)	7 (11.7%)
61–70 years	3 (10.0%)	7 (23.3%)	10 (16.7%)

Table 2 presents the age-wise comparison of maxillary sinus volume between the control and pathological groups. Across all age categories, mean sinus volume was consistently lower in the pathological group compared with the control group. In the 18–30-year age group, the mean sinus volume was 17.42 ± 3.07 in controls versus 10.88 ± 1.35 in the pathological group. Similar reductions were observed in the 31–40-year group (14.57 ± 2.33 vs. 10.95 ± 1.83) and the 41–50-year group (16.00 ± 3.64 vs. 10.34 ± 2.04). The most pronounced difference was noted in individuals aged 51–60 years, where the control group demonstrated a mean volume of 16.48 ± 2.78 compared with 8.70 ± 1.18 in the pathological group. Even in the oldest age group (61–70 years), sinus volume remained lower in the pathological group (10.48 ± 2.40) compared with controls (13.56 ± 2.04).

TABLE 2. Age-wise Comparison of Maxillary Sinus Volume in Control and Pathological Groups

Age Group (years)	Control Group Mean ± SD	Pathological Group Mean ± SD
18–30	17.42 ± 3.07	10.88 ± 1.35
31–40	14.57 ± 2.33	10.95 ± 1.83
41–50	16.00 ± 3.64	10.34 ± 2.04
51–60	16.48 ± 2.78	8.70 ± 1.18
61–70	13.56 ± 2.04	10.48 ± 2.40

Table 3 compares the linear dimensions of the maxillary sinus between the control and pathological groups. The mean sinus length was significantly greater in the control group (26.79 ± 3.86 mm) than in the pathological group (22.94 ± 5.64 mm), with a statistically significant difference (p = 0.001). Similarly, sinus height was significantly reduced in the pathological group (22.23 ± 5.70 mm) compared with the control group (26.85 ± 4.43 mm), also reaching statistical significance (p = 0.001). In contrast, sinus width showed comparable values between the two groups, measuring 21.36 ± 4.07 mm in controls and 21.13 ± 4.77 mm in the pathological group, with no statistically significant difference (p = 0.844).

TABLE 3. Comparison of Maxillary Sinus Dimensions Between Control and Pathological Groups

Dimension (mm)	Control Group (Mean ± SD)	Pathological Group (Mean ± SD)	p-value
Length	26.79 ± 3.86	22.94 ± 5.64	**0.001***
Width	21.36 ± 4.07	21.13 ± 4.77	0.844
Height	26.85 ± 4.43	22.23 ± 5.70	**0.001***

Table 4 details the distribution of pathological findings, severity of mucosal thickening, and the relationship between posterior tooth roots and the sinus floor. Among pathological sinuses, mucosal thickening was the most common finding, observed in 53.3% (16/30) of cases, followed by sinus polyps in 46.7% (14/30). No cases of periostitis, antroliths, mucous retention cysts, or multiple pathologies were identified. Assessment of mucosal thickening severity revealed a statistically significant difference between groups (p = 0.001). While all control sinuses (100%) showed no mucosal thickening, only 46.7% of pathological sinuses were free of thickening. Mild mucosal thickening was present in 20.0% of pathological cases, moderate thickening in 23.3%, and severe thickening in 3.3%. Evaluation of the distance between posterior maxillary tooth roots and the sinus floor showed similar distributions in both groups, with distances ≤2 mm observed in 46.7% of controls and 50.0% of pathological cases, and distances of 2–4 mm in 53.3% and 46.7%, respectively. This difference was not statistically significant ($p = 0.684$), indicating that proximity of posterior tooth roots to the sinus floor alone was not strongly associated with the presence of sinus pathology in this cohort.

TABLE 4. Pathological Findings, Mucosal Thickening, and Tooth Root–Sinus Relationship

Parameter	Category	Control Group (n = 30)	Pathological Group (n = 30)	Total (n = 60)	p-value
Maxillary sinus pathology	Mucosal thickening	—	16 (53.3%)	16 (26.7%)	—
	Sinus polyps	—	14 (46.7%)	14 (23.3%)	—
	Periostitis	—	0 (0%)	0 (0%)	—
	Antroliths	—	0 (0%)	0 (0%)	—
	Mucous retention cysts	—	0 (0%)	0 (0%)	—
	Multiple pathologies	—	0 (0%)	0 (0%)	—
Mucosal thickening severity	None	30 (100%)	14 (46.7%)	44 (73.3%)	0.001*
	Mild	0 (0%)	6 (20.0%)	6 (10.0%)	
	Moderate	0 (0%)	7 (23.3%)	7 (11.7%)	
	Severe	0 (0%)	1 (3.3%)	1 (1.7%)	
Distance between posterior tooth roots and sinus floor (mm)	≤ 2	14 (46.7%)	15 (50.0%)	29 (48.3%)	0.684
	2–4	16 (53.3%)	14 (46.7%)	30 (50.0%)	
	> 4	0 (0%)	1 (3.3%)	1 (1.7%)	

Table 5 shows the results of the correlation analysis between age and maxillary sinus morphometric parameters in both the control and pathological groups. In the control group, age demonstrated weak negative correlations with maxillary sinus volume ($r = -0.18$), length ($r = -0.12$), width ($r = -0.09$), and height ($r = -0.16$); however, none of these associations reached statistical significance ($p > 0.05$). Similarly, in the pathological group, age exhibited weak negative correlations with sinus volume ($r = -0.21$), length ($r = -0.15$), width ($r = -0.11$), and height ($r = -0.19$), with all correlations remaining statistically non-significant ($p > 0.05$).

Table 5. Correlation Between Age and Maxillary Sinus Parameters in Control and Pathological Groups

Parameter	Control Group (r)	p-value	Pathological Group (r)	p-value
Maxillary sinus volume	−0.18	0.34	−0.21	0.26
Sinus length	−0.12	0.52	−0.15	0.43
Sinus width	−0.09	0.64	−0.11	0.58
Sinus height	−0.16	0.39	−0.19	0.31

Correlation coefficients represent Pearson's or Spearman's values as appropriate; p < 0.05 considered statistically significant.

Table 6 shows the results of the multivariate logistic regression analysis identifying independent predictors of maxillary sinus pathology. Reduced maxillary sinus volume emerged as a significant predictor, with an odds ratio of 0.66 (95% CI: 0.52–0.83; $p = 0.001$), indicating that smaller sinus volumes were associated with a higher likelihood of pathological involvement. Similarly, decreases in maxillary sinus length (OR = 0.75; 95% CI: 0.60–0.93; $p = 0.009$) and sinus height (OR = 0.73; 95% CI: 0.58–0.92; $p = 0.007$) were independently associated with the presence of sinus pathology. In contrast, sinus width did not demonstrate a significant association with pathology (OR = 0.96; 95% CI: 0.79–1.17; $p = 0.684$). Demographic variables, including age (OR = 1.02; $p = 0.312$) and gender (OR = 1.20; $p = 0.641$), were not significant predictors after adjustment for sinus morphometric parameters. Additionally, the distance between posterior maxillary tooth roots and the sinus floor was not independently associated with sinus pathology (OR = 1.12; 95% CI: 0.78–1.61; $p = 0.532$).

Table 6. Multivariate Logistic Regression Analysis for Predictors of Maxillary Sinus Pathology

Variable	β Coefficient	Odds Ratio (OR)	95% Confidence Interval	p-value
Age (years)	0.02	1.02	0.98 – 1.06	0.312
Gender (Male vs Female)	0.18	1.20	0.55 – 2.62	0.641
Maxillary sinus volume	−0.41	0.66	0.52 – 0.83	0.001*
Sinus length	−0.29	0.75	0.60 – 0.93	0.009*
Sinus width	−0.04	0.96	0.79 – 1.17	0.684
Sinus height	−0.31	0.73	0.58 – 0.92	0.007*
Distance between posterior tooth roots and sinus floor	0.11	1.12	0.78 – 1.61	0.532

Statistically significant at p < 0.05.

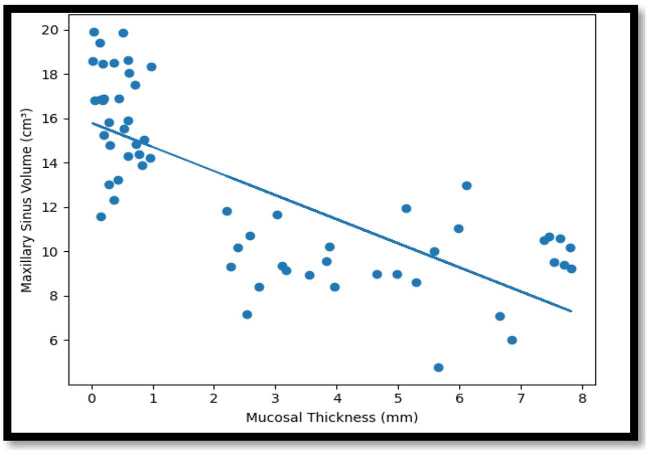

Figure 1. Relationship Between Mucosal Thickness and Maxillary Sinus Volume

Figure 1 shows a scatter plot illustrating the relationship between mucosal thickness and maxillary sinus volume, demonstrating a clear inverse association whereby increasing mucosal thickening is accompanied by a progressive reduction in aerated sinus volume. The fitted regression line with the 95% confidence interval band highlights this trend, and correlation analysis indicates a strong negative association between the two variables (Spearman $r = -0.77$, $p < 0.001$).

V. Discussion

The present CBCT-based study provides a detailed evaluation of maxillary sinus morphology and pathology across healthy and diseased states, with particular emphasis on age-related variations, morphometric differences, and predictors of sinus pathology. The findings contribute clinically relevant evidence supporting the role of CBCT as a reliable imaging modality for comprehensive assessment of the maxillary sinus in dental and maxillofacial practice.

Demographic Profile and Age-related Trends

The demographic distribution in the present study demonstrated equal gender representation in both control and pathological groups, thereby minimizing sex-related confounding. Although the pathological group had a higher mean age compared with controls, both groups shared an identical age range, allowing meaningful age-stratified comparisons. The higher prevalence of sinus pathology in older age groups observed in this study is consistent with previous reports suggesting that chronic inflammatory changes, cumulative environmental exposure, and age-related mucosal alterations may increase susceptibility to maxillary sinus disease with advancing age [1,2].

However, the absence of a statistically significant correlation between age and maxillary sinus volume or dimensions in both groups suggests that chronological aging alone is not a primary determinant of sinus morphometry. This finding aligns with CBCT-based studies by Ozsoy et al. and Madfa et al., who reported that although sinus morphology varies across age groups, disease-related changes exert a stronger influence than age itself [8,13]. Thus, age may act as a modifying factor rather than a direct predictor of maxillary sinus pathology.

Maxillary Sinus Volume Changes in Health and Disease

One of the key findings of this study was the consistently reduced maxillary sinus volume in the pathological group across all age categories. The most pronounced reduction was observed in the 51–60-year age group, where pathological sinuses demonstrated nearly half the mean volume of controls. This observation is clinically significant and supports the hypothesis that chronic inflammatory processes, mucosal hypertrophy, and polypoidal changes can substantially reduce functional sinus volume.

Previous CBCT and CT-based studies have reported similar findings, attributing volume reduction to thickening of the Schneiderian membrane, partial opacification, and bony remodeling secondary to chronic inflammation [1,5,15]. Dogan et al., in a large CBCT analysis, demonstrated that mucosal thickening and polypoidal changes were strongly associated with decreased aerated sinus volume, particularly in chronic sinusitis cases [6]. The present findings reinforce these observations and highlight the importance of volumetric assessment rather than reliance on linear dimensions alone.

From a clinical perspective, reduced sinus volume has direct implications for dental implant planning, sinus floor elevation procedures, and assessment of surgical risk. Reduced aerated space may increase the likelihood of membrane perforation during sinus augmentation and may necessitate preoperative management of sinus pathology [16].

Linear Dimensions of the Maxillary Sinus

The present study demonstrated statistically significant reductions in maxillary sinus length and height in the pathological group, while sinus width remained comparable between groups. This selective dimensional reduction suggests that pathological changes predominantly affect the vertical and anteroposterior dimensions of the sinus.

These findings are in agreement with earlier CBCT studies indicating that inflammatory mucosal changes are most pronounced along the sinus floor and roof, leading to a reduction in sinus height, while anterior and posterior wall involvement contributes to reduced length [17,18]. In contrast, the mediolateral width of the sinus is largely determined by the zygomatic and lateral maxillary walls, which are less susceptible to inflammatory remodeling, explaining the absence of significant width differences.

Clinically, reduced sinus height is particularly relevant in posterior maxillary implant planning, as it directly influences available bone height and the need for sinus augmentation. The findings underscore the necessity of evaluating sinus health before dental procedures that involve the posterior maxilla [19].

Pattern and Spectrum of Maxillary Sinus Pathology

Mucosal thickening was the most prevalent pathological finding in the present study, followed by sinus polyps, while no cases of periostitis, antroliths, or mucous retention cysts were observed. This distribution is consistent with the literature, where mucosal thickening is widely reported as the most common incidental or symptomatic CBCT finding in the maxillary sinus [6,20,21].

The significant difference in mucosal thickening severity between control and pathological groups further emphasizes its diagnostic relevance. Nearly half of the pathological group exhibited mild to moderate mucosal thickening, with a small proportion showing severe involvement. According to established radiologic criteria, mucosal thickening greater than 2–3 mm is considered pathologic and often reflects chronic inflammatory changes [22].

The predominance of inflammatory mucosal changes observed in this study supports the growing recognition that odontogenic and non-odontogenic inflammatory processes contribute substantially to maxillary sinus disease. Several authors have emphasized that dental pathology, even in the absence of overt symptoms, can trigger or perpetuate sinus inflammation [23,24].

Tooth Root–Sinus Relationship and Odontogenic Influence

An important finding of the present study was the lack of a statistically significant association between posterior maxillary tooth root proximity to the sinus floor and the presence of sinus pathology. Although nearly half of both control and pathological groups demonstrated root-to-sinus distances of ≤2 mm, this proximity alone did not predict pathology.

This finding aligns with CBCT studies by Maillet et al. and Nascimento et al., who reported that while close root proximity may increase the risk of odontogenic sinusitis in the presence of periapical pathology, proximity alone is insufficient to cause sinus disease [25,26]. Instead, the presence of periapical infection, periodontal disease, or iatrogenic factors plays a more decisive role.

These results have important clinical implications, as they caution against over-attribution of sinus pathology solely to anatomical proximity and emphasize the need for comprehensive evaluation of dental and sinus health.

Correlation Analysis and Age Independence

The absence of significant correlations between age and sinus volume or dimensions in both groups further strengthens the argument that pathological alterations dominate over physiological aging in determining sinus morphology. Similar findings have been reported in volumetric CBCT studies, which suggest that while sinus size may stabilize after skeletal maturity, disease-related remodeling can occur at any age [8,15].

This observation reinforces the importance of individualized radiologic assessment rather than reliance on age-based assumptions when interpreting sinus dimensions.

Logistic Regression and Predictors of Sinus Pathology

Multivariate logistic regression analysis identified reduced maxillary sinus volume, decreased sinus length, and reduced sinus height as significant independent predictors of maxillary sinus pathology. In contrast, age, gender, sinus width, and tooth root–sinus distance were not significant predictors.

These findings are particularly valuable, as they demonstrate that morphometric reductions are not merely consequences of sinus disease but can serve as predictive indicators of pathology. Few CBCT studies have applied multivariate models to identify predictors of sinus disease, making this analysis a notable strength of the present study [18].

The identification of volume and vertical and anteroposterior dimensions as predictors underscores the clinical relevance of comprehensive morphometric evaluation. These parameters may aid in early detection of subclinical disease and risk stratification in patients undergoing dental or surgical interventions involving the maxillary sinus.

Clinical Implications

The findings of this study have several practical implications. First, CBCT should be considered the imaging modality of choice for detailed evaluation of the maxillary sinus in patients undergoing posterior maxillary dental procedures. Second, volumetric and dimensional analysis should be integrated into routine CBCT interpretation rather than relying solely on qualitative assessment. Third, the presence of reduced sinus volume and height should prompt careful evaluation for underlying pathology, even in asymptomatic patients.

VI. Limitations and Future Directions

Despite its strengths, this study has certain limitations. The retrospective design limits causal inference, and the sample size, while adequate for preliminary analysis, may limit generalizability. Additionally, clinical correlation with symptoms and endoscopic findings was not available. Future prospective studies with larger samples, bilateral analysis, and correlation with clinical and microbiological data would further strengthen understanding of maxillary sinus pathology.

VII. Conclusion

This CBCT-based study demonstrates that maxillary sinus pathology is associated with significant reductions in sinus volume, length, and height, while sinus width remains largely unaffected. Mucosal thickening was the most common pathological finding and served as a key indicator of sinus disease. Age did not show a significant association with sinus morphometry, indicating that pathological changes have a greater influence than chronological aging. Proximity of posterior tooth roots to the sinus floor was not an independent predictor of sinus pathology. Overall, quantitative CBCT assessment provides valuable diagnostic insight and should be routinely incorporated into evaluation and treatment planning involving the maxillary sinus.

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