Original Article

Radiographic Characterisation of Maxillary Sinus Pneumatization and Posterior Root Relationship – A Cone Beam Computed Tomographic Study

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ABSTRACT

Background: The anatomical relationship between the maxillary sinus and posterior maxillary teeth is of considerable clinical importance during implant placement, endodontic surgery, sinus augmentation procedures, and tooth extraction. Maxillary sinus pneumatization may alter available bone height and influence root proximity to the sinus floor. Cone Beam Computed Tomography (CBCT) provides accurate three-dimensional assessment of these anatomical relationships. **Materials and Methods:** A retrospective observational study was conducted using 423 CBCT scans obtained from subjects fulfilling the inclusion criteria. Maxillary sinus pneumatization was assessed using a Nasal Spine-Guided Classification system and categorized as Class I, Class II, or Class III. Root–sinus relationships were classified into Type I, Type II, and Type III categories. Associations between demographic variables and sinus classifications were analyzed using the Chi-square test. Correlations among continuous variables were evaluated using Spearman's rank correlation coefficient. Statistical significance was set at $p < 0.05$. **Results:** Class III pneumatization was the predominant pattern on both the left and right sides. No statistically significant association was observed between gender and maxillary sinus classification on either side ($p > 0.05$). Similarly, age group showed no significant association with sinus classification ($p > 0.05$). Type II root–sinus relationship was the most frequently observed pattern in both males and females. A weak positive correlation was observed between right edentulous height and Schneiderian membrane thickness ($\rho = 0.133$, $p = 0.006$). A second weak positive correlation was found between right pneumatization and right interradicular height ($\rho = 0.108$, $p = 0.026$). **Conclusion:** Advanced maxillary sinus pneumatization was commonly observed in the study population. The anatomical relationship between posterior maxillary teeth and the sinus floor remained consistent across age and gender groups. CBCT provides valuable three-dimensional information that may assist clinicians in implant planning, endodontic surgery, and management of posterior maxillary pathologies.

Key words: Cone Beam Computed Tomography, Maxillary Sinus, Pneumatization, Root-Sinus Relationship, Schneiderian Membrane, Posterior Maxillary Teeth

INTRODUCTION

The maxillary sinus is the largest paranasal sinus and occupies a substantial portion of the maxillary bone. Owing to its close anatomical relationship with the roots of maxillary premolars and molars, it represents one of the most clinically relevant structures encountered in oral and maxillofacial practice.[1,2] Variations in sinus anatomy may influence dental extractions, implant placement, sinus augmentation procedures, and endodontic surgery.[3]

Maxillary sinus pneumatization refers to the physiological expansion of the sinus cavity into the surrounding alveolar process.[3,4] Following tooth loss, progressive alveolar bone resorption combined with continued sinus expansion may result in significant reduction of available bone height. Such changes often complicate implant placement and may necessitate additional surgical procedures including sinus floor elevation and bone grafting.[5]

The proximity of posterior tooth roots to the maxillary sinus floor has also been associated with odontogenic sinusitis, root displacement during extraction, sinus membrane perforation, and surgical complications.[6,7] Accurate assessment of root–sinus

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relationships is therefore essential before undertaking invasive dental procedures.

Conventional radiographic techniques such as panoramic radiography and periapical imaging provide limited information due to magnification, distortion, and superimposition of anatomical structures.[8,9] Cone Beam Computed Tomography (CBCT) overcomes these limitations by providing high-resolution three-dimensional visualization of the maxillofacial region with relatively low radiation exposure.[10]

The present study was undertaken to radiographically characterize maxillary sinus pneumatization and evaluate its relationship with posterior maxillary teeth using CBCT.

MATERIALS AND METHODS

This retrospective observational study was conducted in the Department of Oral Medicine and Radiology after obtaining institutional approval. A total of 423 CBCT scans fulfilling the inclusion criteria were selected for analysis. CBCT scans showing fully erupted posterior maxillary teeth with complete root formation and clear visualization of the maxillary sinus floor were included.

Scans with motion artefacts, previous sinus surgery, implant placement, facial trauma, developmental anomalies, or incomplete visualization of the posterior maxilla were excluded.

All CBCT images were reconstructed in Digital Imaging and Communications in Medicine (DICOM) format and evaluated using dedicated CBCT imaging software. Multiplanar reconstruction views including axial, coronal, and sagittal sections were used for analysis.

Assessment of Maxillary Sinus Pneumatization

The degree of sinus pneumatization was evaluated using a Nasal Spine-Guided Classification system.[1,11] The anterior nasal spine served as the reference landmark, and measurements were obtained on standardized CBCT sections to determine the extent of inferior sinus extension (Figure 1).

- Class I: 0–4 mm
- Class II: 5–8 mm
- Class III: >8 mm

The distance of sinus pneumatization from the anterior nasal spine reference line was measured and subsequently categorized into Class I, Class II, and Class III groups according to the established classification criteria (Figure 2).

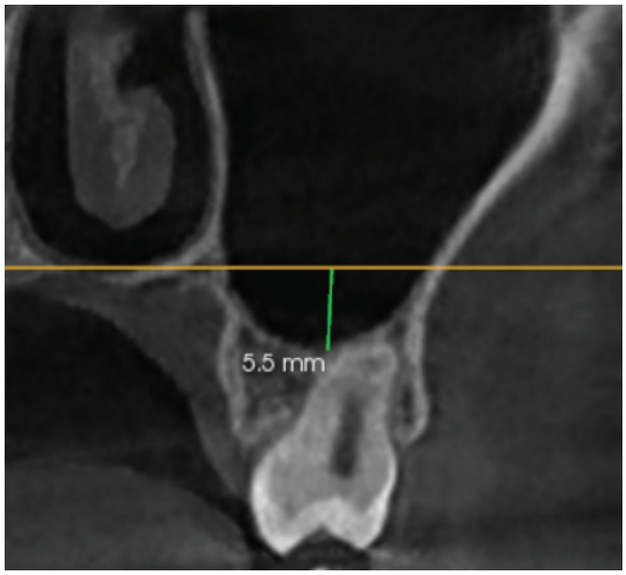

Figure 2: Measurement of Maxillary Sinus Pneumatization Distance

Assessment of Root–Sinus Relationship

The relationship between posterior maxillary roots and the sinus floor was categorized as:

- Type I – Root apex separated from sinus floor
- Type II – Root apex in contact with sinus floor
- Type III – Sinus floor extending between roots

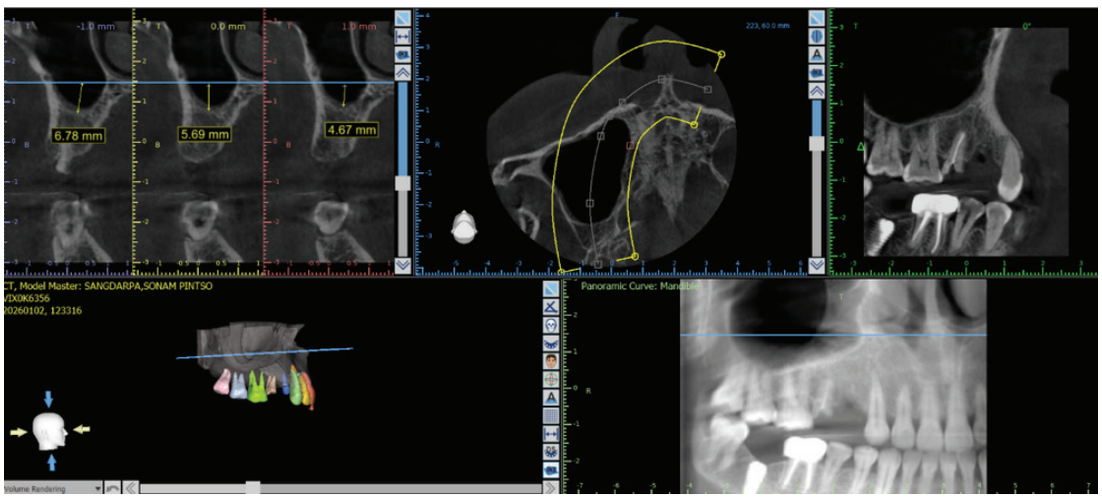

Figure 1: Assessment of Maxillary Sinus Pneumatization Using the Nasal Spine-Guided Classification Method

Assessment of Schneiderian Membrane Thickness

Schneiderian membrane thickness was evaluated on sagittal CBCT sections. The deepest point of the maxillary sinus floor was identified, and the thickness of the sinus mucosa was measured perpendicular to the underlying cortical boundary.[12] Additional measurements were obtained at the highest point of the sinus cavity, and the recorded values were used for subsequent statistical evaluation (Figure 3).

Figure 3: Measurement of Schneiderian Membrane Thickness

Statistical Analysis

Data were analyzed using SPSS software. Chi-square tests were used to evaluate associations between categorical variables. Spearman's rank correlation coefficient was applied to determine relationships among continuous variables. A p-value <0.05 was considered statistically significant.

RESULTS

The radiographic findings obtained from the 423 CBCT scans were analyzed to determine the prevalence of different sinus pneumatization patterns and their relationship with demographic and anatomical variables.

Gender and Maxillary Sinus Classification

On the left side, Class III pneumatization was observed in 53.1% of females and 56.1% of males. On the right side, Class III pneumatization was observed in 52.1% of females and 57.1% of males. No statistically significant association was observed between gender and left-side classification ($\chi^2 = 0.471$, p = 0.790) or right-side classification ($\chi^2 = 1.448$, p = 0.485) (Table 1 A & B).

Table 1: Association Between Gender and Maxillary Sinus Pneumatization Classification

Left-Side Classification

Classification	Female n (%)	Male n (%)
Class I	37 (17.5)	33 (15.6)
Class II	62 (29.4)	60 (28.3)
Class III	112 (53.1)	119 (56.1)

Chi-square = 0.471, df = 2, p = 0.790

Right-Side Classification

Classification	Female n (%)	Male n (%)
Class I	32 (15.2)	25 (11.8)
Class II	69 (32.7)	66 (31.1)
Class III	110 (52.1)	121 (57.1)

Chi-square = 1.448, df = 2, p = 0.485

Gender and Root–Sinus Relationship

Type II root–sinus relationship was the predominant pattern in both genders, accounting for 60.2% of females and 59.4% of males. No statistically significant association was observed between gender and root–sinus relationship ($\chi^2 = 0.857$, p = 0.652) (Table 2).

Table 2: Association Between Gender and Root–Sinus Relationship

Root–Sinus Relationship	Female n (%)	Male n (%)
Type I	42 (19.9)	37 (17.5)
Type II	127 (60.2)	126 (59.4)
Type III	42 (19.9)	49 (23.1)

Chi-square = 0.857, df = 2, p = 0.652

Age Group and Maxillary Sinus Classification

Class III pneumatization remained the most common pattern across all age groups. No statistically significant association was found between age group and left-side classification ($\chi^2 = 3.931$, p = 0.686) or right-side classification ($\chi^2 = 0.588$, p = 0.997) (Table 3 A & B).

Table 3: Association Between Age Group and Maxillary Sinus Pneumatization Classification

Left Side

Age Group (Years)	Class I	Class II	Class III
≤30	27	33	65
31–45	20	46	80
46–60	22	40	80
>60	1	3	6

Chi-square = 3.931, df = 6, p = 0.686

Right Side

Age Group (Years)	Class I	Class II	Class III
≤30	18	38	69
31–45	19	48	79
46–60	19	45	78
>60	1	4	5

Chi-square = 0.588, df = 6, p = 0.997

Correlation Analysis

Spearman correlation analysis demonstrated a weak positive correlation between right edentulous alveolar height and Schneiderian membrane thickness ($\rho = 0.133$, $p = 0.006$). A second weak positive correlation was identified between right maxillary sinus pneumatization and right interradicular bone height ($\rho = 0.108$, $p = 0.026$) (Table 4).

Table 4: Significant Spearman Correlations Among Study Variables

Variable 1	Variable 2	Spearman's ρ	p-value
Right Edentulous Height (mm)	Right Schneiderian Membrane Thickness (mm)	0.133	0.006*
Right Pneumatization (mm)	Right Interradicular Height (mm)	0.108	0.026*

*Statistically significant at $p < 0.05$

DISCUSSION

The present retrospective CBCT study was conducted to evaluate maxillary sinus pneumatization patterns and their relationship with posterior maxillary teeth in a sample of 423 subjects. Particular emphasis was placed on assessing sinus pneumatization using the Nasal Spine-Guided Classification system and evaluating root–sinus relationships, Schneiderian membrane thickness, and associated anatomical parameters.

In the present study, Class III pneumatization was the most prevalent pattern on both the left and right sides. Among females, Class III pneumatization accounted for 53.1% on the left side and 52.1% on the right side, whereas among males it accounted for 56.1% and 57.1%, respectively. No statistically significant association was observed between gender and sinus classification on either side. These findings are consistent with those reported by Kabli et al.,1 who also demonstrated a predominance of Class III pneumatization in a Saudi population, with Class III accounting for 56.57% and 53.15% of left and right maxillary sinuses, respectively. The similarity of findings between studies supports the reproducibility and clinical applicability of the Nasal Spine-Guided Classification system for assessing alveolar extension of the maxillary sinus.

The predominance of advanced pneumatization observed in the present study may be explained by the natural tendency of the maxillary sinus to expand inferiorly toward the alveolar process following skeletal maturation.[13] Progressive remodeling of the sinus floor, together with age-related alveolar bone changes, contributes to the development of deeper sinus recesses in the posterior maxilla. Advanced sinus pneumatization is of particular clinical importance because it may reduce available bone height for implant placement and increase the complexity of sinus augmentation procedures.[14]

Gender did not significantly influence maxillary sinus classification in the present investigation. Similar observations have been reported by Alassaf et al., who found no significant sex-related differences in maxillary sinus anatomical variations.[15] The absence of gender-related differences suggests that sinus pneumatization is primarily governed by developmental and anatomical factors rather than sexual dimorphism.

The present study also evaluated the influence of age on maxillary sinus classification. Although Class III pneumatization remained the most frequent pattern across all age groups, no statistically significant association was identified between age and sinus classification. These findings are comparable to those reported by Wu et al., who demonstrated that although minor variations may occur with advancing age, the overall extent of maxillary sinus pneumatization remains relatively stable in adult populations.[16] Such findings indicate that age alone may not be a strong determinant of sinus floor position once skeletal growth has been completed.

Evaluation of the root–sinus relationship demonstrated that Type II configuration was the most common anatomical pattern, representing 60.2% of females and 59.4% of males.[17] No statistically significant association was observed between gender and root–sinus relationship. The predominance of Type II relationships indicates that direct contact between posterior root apices and the sinus floor is a frequent anatomical finding.[18] This observation agrees with previous CBCT investigations that have demonstrated close proximity between posterior maxillary roots and the maxillary sinus floor in a substantial proportion of individuals.1 Such anatomical relationships are clinically relevant because they may increase the risk of oroantral communication, odontogenic sinusitis, sinus membrane perforation, and displacement of root fragments during extraction procedures.

The close root–sinus relationship observed in the present study further highlights the importance of three-dimensional radiographic assessment prior to surgical interventions involving posterior maxillary teeth. Conventional panoramic radiography often overestimates root penetration into the sinus because of image superimposition, whereas CBCT permits accurate assessment of the true anatomical relationship between roots and the sinus floor. This reinforces the growing role of CBCT as an essential diagnostic tool in implantology, endodontics, oral surgery, and periodontology.[19]

Correlation analysis demonstrated a weak but statistically significant positive association between right edentulous alveolar height and Schneiderian membrane thickness ($\rho = 0.133$, $p = 0.006$). This finding suggests that variations in alveolar bone morphology may influence sinus mucosal characteristics.[20] Although the correlation strength was limited, it may reflect adaptive physiological responses of the Schneiderian membrane to local anatomical changes or functional remodeling of the sinus cavity.

A second weak positive correlation was observed between right maxillary sinus pneumatization and right interradicular bone height ($\rho = 0.108$, $p = 0.026$). These findings indicate a potential relationship between sinus expansion and adjacent osseous structures. However, the relatively low correlation coefficients suggest that additional factors, including tooth position, alveolar bone quality, occlusal loading, and individual anatomical variability, may contribute to the observed relationships.

Unlike the findings reported by Kabli et al., who observed no significant correlation between membrane thickness and sinus pneumatization in edentulous regions, the present study demonstrated a statistically significant relationship between edentulous height and membrane thickness.[1,21] Differences in sample characteristics, measurement protocols, and population demographics may account for this variation. Nevertheless, both studies support the concept that Schneiderian membrane behavior is multifactorial and cannot be explained solely by sinus pneumatization.

Overall, the findings of the present study demonstrate that advanced maxillary sinus pneumatization is a common anatomical feature and that close root–sinus relationships are frequently encountered in the posterior maxilla. These anatomical characteristics should be carefully considered during treatment planning for implant placement, sinus floor elevation, apical surgery, and extraction procedures. CBCT remains the most reliable imaging modality for comprehensive assessment of these relationships and contributes significantly to improved surgical safety and treatment outcomes.

CONCLUSION

Class III maxillary sinus pneumatization was the predominant anatomical pattern observed in the present study.

Neither age nor gender demonstrated a significant influence on maxillary sinus classification.

Type II root–sinus relationship was the most frequently observed anatomical configuration.

Weak but statistically significant correlations were identified between Schneiderian membrane thickness and edentulous height, as well as between sinus pneumatization and interradicular bone height.

CBCT provides a reliable and comprehensive method for evaluating maxillary sinus anatomy and should be considered an essential diagnostic tool during implant planning and surgical management of the posterior maxilla.

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