Evaluation of Maxillary Sinus Anatomy Using CBCT for Safe Sinus Lift Procedures

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ABSTRACT:

Background:

Successful implant rehabilitation in the posterior maxilla requires a thorough understanding of maxillary sinus anatomy. Anatomical variations such as reduced residual alveolar bone height, Schneiderian membrane thickness, sinus septa, maxillary sinus pneumatization, and the course of the posterior superior alveolar artery (PSAA) may influence the safety and predictability of sinus floor elevation procedures. Cone-beam computed tomography (CBCT) provides three-dimensional visualization, enabling comprehensive preoperative assessment of these anatomical structures.

Aim:

To evaluate the anatomical characteristics of the maxillary sinus using CBCT and determine their clinical relevance for planning safe sinus floor elevation procedures.

Materials and Methods:

A retrospective observational study was conducted on CBCT scans of 60 adult patients (120 maxillary sinuses). Residual alveolar bone height, Schneiderian membrane thickness, maxillary sinus pneumatization, sinus septa, and PSAA visibility were assessed. Data were analyzed using Statistical Package for the Social Sciences (SPSS) Statistics version 26.0. Descriptive statistics were expressed as mean ± standard deviation (SD), standard error (SE), and 95% confidence intervals (CI). Independent-samples Student's t-test was used for group comparisons, Pearson's correlation coefficient assessed the relationship between residual bone height and sinus pneumatization, and binary logistic regression identified factors associated with reduced residual alveolar bone height. Statistical significance was set at $p < 0.05$.

Results:

The mean residual alveolar bone height was 5.82 ± 2.04 mm (95% CI: 5.45–6.19 mm), while the mean Schneiderian membrane thickness was 1.73 ± 0.61 mm (95% CI: 1.62–1.84

mm). Residual bone height was significantly lower in sinuses with extensive pneumatization than in those with mild-to-moderate pneumatization (4.68 ± 1.52 mm vs. 6.85 ± 1.74 mm; t = 7.21, p = 0.001). Schneiderian membrane thickness was significantly greater in sinuses with septa than in those without septa (1.94 ± 0.63 mm vs. 1.62 ± 0.58 mm; t = 2.71, p = 0.001). The PSAA was identified in 79.2% of the evaluated sinuses. A significant moderate negative correlation was observed between residual alveolar bone height and the degree of sinus pneumatization (r = −0.58, p < 0.001). Binary logistic regression demonstrated that extensive sinus pneumatization was an independent predictor of reduced residual alveolar bone height (OR = 3.12; 95% CI: 1.61–6.05; p = 0.001).

Conclusion:

CBCT provides valuable three-dimensional information regarding maxillary sinus anatomy that is essential for implant treatment planning. Extensive maxillary sinus pneumatization is significantly associated with reduced residual alveolar bone height, while the presence of sinus septa is associated with increased Schneiderian membrane thickness. The high prevalence of radiographically detectable PSAA further highlights the importance of CBCT-based preoperative assessment to facilitate safe sinus floor elevation procedures and reduce the risk of surgical complications.

Keywords: CBCT, Dental Implants, Maxillary Sinus, Posterior Maxilla, Schneiderian Membrane, Sinus Floor Elevation, Sinus Septa

Introduction

Dental implants have become the treatment of choice for restoring missing teeth because of their high survival rates, excellent functional outcomes, and favorable esthetic results. Implant rehabilitation in the posterior maxilla, however, remains clinically challenging due to progressive alveolar bone resorption following tooth loss and continuous expansion of the maxillary sinus. These anatomical changes often reduce the available bone height, making primary implant placement difficult without prior augmentation procedures [1, 2].

Maxillary sinus floor elevation is a well-established surgical technique used to increase bone volume in the posterior maxilla, thereby facilitating successful implant placement. The long-term outcome of this procedure depends not only on surgical expertise but also on a detailed understanding of the anatomical characteristics of the maxillary sinus. Variations in sinus morphology, including the presence of sinus septa, changes in Schneiderian membrane thickness, degree of sinus pneumatization, residual alveolar bone height, and vascular anatomy, may significantly influence the complexity of surgery and the likelihood of intraoperative and postoperative complications [3,4].

Among these anatomical factors, sinus septa may complicate membrane elevation and increase the risk of membrane perforation, whereas an excessively thick or inflamed Schneiderian membrane may be associated with impaired sinus health and compromised graft stability. Likewise, extensive sinus pneumatization and limited residual bone height often determine the need for either a lateral window or transcrestal sinus augmentation approach. Accurate identification of these anatomical features before surgery is therefore essential for selecting an appropriate treatment strategy and minimizing surgical complications [5, 6].

Traditional two-dimensional radiographic techniques, including panoramic and periapical radiographs, provide only limited diagnostic information because of image distortion, magnification errors, and superimposition of surrounding anatomical structures. These limitations reduce the accuracy of linear measurements and restrict the clinician's ability to appreciate the three-dimensional anatomy of the maxillary sinus, which is critical during implant treatment planning [7].

Cone-Beam Computed Tomography (CBCT) has become the imaging modality of choice for preoperative evaluation of the posterior maxilla owing to its ability to generate high-resolution three-dimensional images with relatively low radiation exposure compared with conventional computed tomography. CBCT permits accurate assessment of residual alveolar bone dimensions, Schneiderian membrane thickness, sinus septa, sinus pneumatization, sinus pathology, and the course of the posterior superior alveolar artery. This comprehensive anatomical evaluation enables clinicians to anticipate potential surgical difficulties, improve treatment planning, and reduce the incidence of complications such as membrane perforation, hemorrhage, graft failure, and implant loss [8–10].

Several radiographic investigations have demonstrated considerable variation in maxillary sinus anatomy among different populations, highlighting the importance of population-specific anatomical assessment. A thorough understanding of these variations is fundamental for selecting appropriate sinus augmentation techniques, improving surgical safety, and enhancing the long-term success of implant-supported rehabilitation [11, 12].

Therefore, the present study was designed to evaluate the anatomical characteristics of the maxillary sinus using CBCT and to determine their relevance in planning safe sinus lift procedures. Particular emphasis was placed on the assessment of residual alveolar bone height, Schneiderian membrane thickness, sinus septa, sinus pneumatization, vascular anatomy, and other clinically significant anatomical landmarks that may influence surgical decision-making and treatment outcomes.

Materials & Methods

Study Design

A retrospective observational study was carried out to investigate the anatomical characteristics of the maxillary sinus using CBCT and to determine their relevance in planning safe sinus floor elevation procedures. The study protocol complied with the ethical principles outlined in the Declaration of Helsinki and was approved by the Institutional Ethics Committee before data collection. All patient information was anonymized to ensure confidentiality.

Study Population

The study included 60 adult patients, comprising 120 maxillary sinuses, who underwent CBCT examination as part of preoperative planning for implant rehabilitation in the posterior maxillary region. CBCT datasets were retrieved retrospectively from the institutional radiology archive.add department of Prosthodontics and Crown & Bridge

Inclusion Criteria

- Patients were considered eligible if they met the following criteria:
- Age 18 years or older
- Availability of CBCT scans showing complete visualization of one or both maxillary sinuses
- Patients indicated for implant-supported rehabilitation in the posterior maxilla
- Diagnostic-quality CBCT images free from motion artifacts or significant distortion

Exclusion Criteria

- CBCT scans were excluded under the following conditions:
- Previous history of sinus floor augmentation or other maxillary sinus surgical procedures

- Craniofacial developmental anomalies, facial trauma, or maxillary fractures
- Presence of large cystic lesions, tumors, or other pathological conditions involving the maxillary sinus
- CBCT images with inadequate quality for accurate anatomical assessment
- Incomplete clinical or radiographic records

CBCT Acquisition Protocol

All CBCT examinations were performed using the same imaging system under standardized CBCT Acquisition Protocol CBCT scans were obtained using the Planmeca ProMax® 3D Mid imaging system (Planmeca Oy, Helsinki, Finland). All examinations were conducted following a standardized imaging protocol to ensure consistency across the study. Patients were positioned in an upright standing posture, with the Frankfort horizontal plane maintained parallel to the floor throughout image acquisition. The exposure settings were standardized at 90 kVp tube voltage, 10 mA tube current, an exposure time of 10–15 seconds, a 0.2 mm isotropic voxel size, and a 10 × 10 cm field of view (FOV). Following image acquisition, the volumetric datasets were reconstructed and examined using Planmeca Romexis® software (Planmeca Oy, Helsinki, Finland). Radiographic assessment was performed by reviewing multiplanar reconstructions in the axial, coronal, and sagittal planes, together with three-dimensional volume-rendered images, to facilitate comprehensive evaluation of the anatomical features of the maxillary sinus.

Radiographic Assessment

All CBCT images were independently interpreted by two experienced oral and maxillofacial radiologists. Whenever discrepancies occurred, the images were reviewed jointly until a consensus was achieved.

The following anatomical variables were recorded.

Residual Alveolar Bone Height

Residual bone height was measured as the vertical distance from the crest of the alveolar ridge to the floor of the maxillary sinus at the intended implant site on coronal CBCT sections. Measurements were recorded in millimeters (mm).

Schneiderian Membrane Thickness

The thickness of the Schneiderian membrane was measured at its maximum dimension adjacent to the sinus floor. Membranes measuring more than 2 mm were classified as thickened.

Maxillary Sinus Septa

The presence, number, orientation, and location of sinus septa were documented and categorized according to their anatomical position as anterior, middle, or posterior.

Degree of Sinus Pneumatization

Sinus pneumatization was assessed according to the extent of inferior expansion of the sinus into the alveolar process and classified as mild, moderate, or extensive.

Posterior Superior Alveolar Artery (PSAA)

The PSAA was evaluated for its visibility and anatomical course within the lateral wall of the maxillary sinus whenever clearly identifiable on CBCT images.

Maxillary Sinus Dimensions

Linear measurements of the sinus were obtained by determining the maximum mediolateral width and superoinferior height on the appropriate coronal and sagittal sections.

Additional Anatomical Findings

Other clinically relevant observations, including accessory septa, mucosal thickening, odontogenic pathology, retained roots, and additional anatomical variations that could influence sinus augmentation procedures, were also recorded.

Observer Reliability

Before commencing the study, both radiologists underwent calibration using 20 CBCT scans that were not included in the final sample. Inter-observer agreement was evaluated using Cohen's kappa coefficient, while intra-observer reliability was determined by repeating measurements after a two-week interval. A kappa coefficient greater than 0.80 was considered indicative of excellent agreement.

Statistical Analysis

The collected data were entered into Microsoft Excel and analyzed using Statistical Package for the Social Sciences (SPSS) Statistics, version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables, including residual alveolar bone height and Schneiderian membrane thickness, were assessed for normality using the Shapiro–Wilk test. As the data followed a normal distribution, descriptive statistics were reported as mean ± standard deviation (SD), together with the standard error (SE) and 95% confidence intervals (CI). Categorical variables, including the visibility of the PSAA, were summarized using frequencies and percentages.

Comparisons of mean residual alveolar bone height between sinuses exhibiting extensive and mild/moderate pneumatization, as well as comparisons of Schneiderian membrane thickness between sinuses with and without septa, were performed using the independent samples Student's t-test. The association between residual alveolar bone height and the extent of maxillary sinus pneumatization was examined using Pearson's correlation coefficient (r), and the corresponding 95% CI was calculated to evaluate the precision of the estimated correlation.

To determine the independent variables associated with reduced residual alveolar bone height, binary logistic regression analysis was conducted. Regression coefficients (β), odds ratios (ORs), 95% confidence intervals (CIs), Wald chi-square statistics, and corresponding p-values were computed. All statistical analyses were two-tailed, and a p-value < 0.05 was considered indicative of statistical significance.

Results

Table 1 & Figure 1 illustrate that the mean residual alveolar bone height of the assessed maxillary sinuses was 5.82 ± 2.04 mm, reflecting a moderate amount of available bone for implant placement in the posterior maxilla. The SE (0.19 mm) demonstrates a reliable estimate of the sample mean. Furthermore, the 95% CI (5.45–6.19 mm) indicates that the actual population means residual alveolar bone height is likely to fall within this range. These findings suggest that many of the examined sites had limited residual bone volume, emphasizing the importance of careful preoperative evaluation and indicating that sinus floor elevation procedures may be required in a substantial number of cases to achieve predictable implant placement.

Table 1: Residual Alveolar Bone Height

Statistic	Value
Mean (mm)	5.82
SD	2.04
SE	0.19
95% CI	5.45–6.19

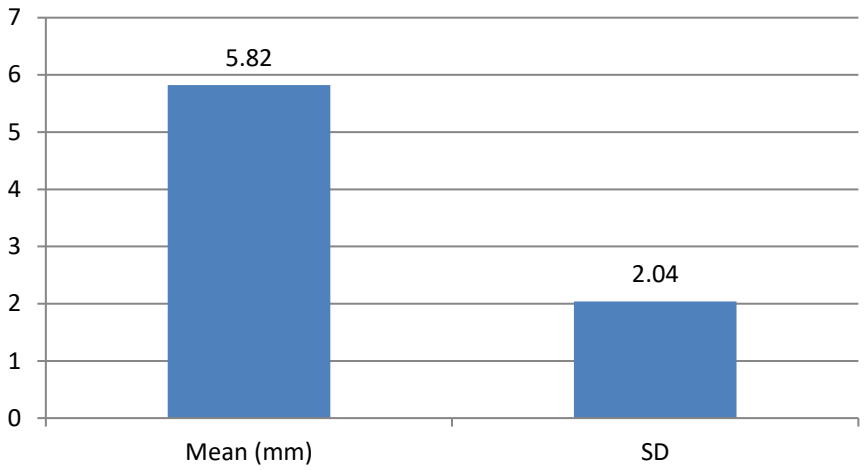

Figure 1: Distribution of Mean Residual Alveolar Bone Height in the Evaluated Maxillary Sinuses

Table 2 & Figure 2 present the Schneiderian membrane thickness measured in the evaluated maxillary sinuses. The mean membrane thickness was 1.73 ± 0.61 mm, indicating relatively low variation among the examined sinuses. The SE (0.06 mm) reflects a precise estimate of the sample mean. In addition, the 95% CI (1.62–1.84 mm) suggests that the true mean Schneiderian membrane thickness of the target population is likely to fall within this range. Overall, the average membrane thickness was within the normal physiological limits; however, individual differences in membrane thickness may influence surgical planning, as thicker or thinner membranes can affect membrane manipulation and the likelihood of perforation during sinus floor elevation procedures.

Table 2: Schneiderian Membrane Thickness

Statistic	Value
Mean (mm)	1.73
SD	0.61
SE	0.06
95% CI	1.62–1.84

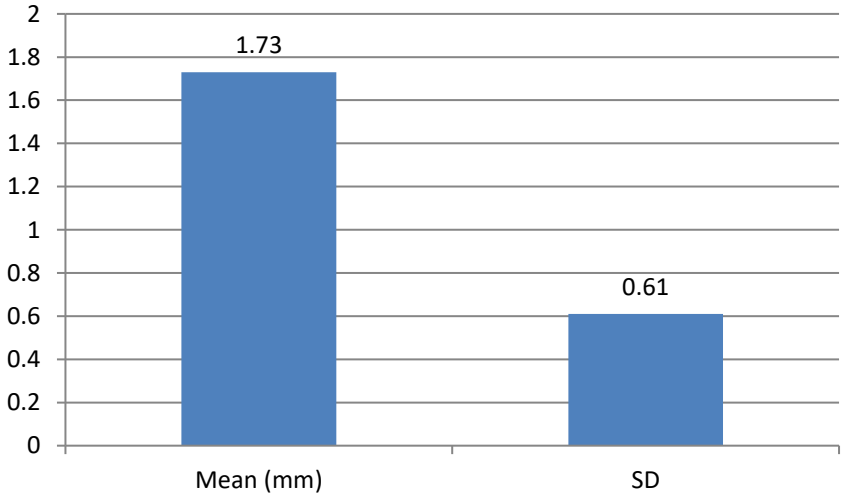

Figure 2: Distribution of Schneiderian Membrane Thickness in the Evaluated Maxillary Sinuses

Table 3 & Figure 3 compare the residual alveolar bone height between maxillary sinuses with extensive pneumatization and those with mild to moderate pneumatization. The extensive pneumatization group (n = 57) exhibited a mean residual alveolar bone height of 4.68 ± 1.52 mm, while the mild to moderate pneumatization group (n = 63) demonstrated a significantly higher mean value of 6.85 ± 1.74 mm. The corresponding standard errors (0.20 mm and 0.22 mm, respectively) indicate that the mean estimates for both groups were determined with good precision. Statistical analysis using the independent-samples Student's t-test revealed a highly significant difference between the two groups (t = 7.21, p = 0.001). These findings indicate that extensive maxillary sinus pneumatization is associated with a marked reduction in residual alveolar bone height, thereby increasing the likelihood that sinus floor augmentation may be necessary before implant placement in the posterior maxilla.

Table 3: Bone Height by Pneumatization

Group	n	Mean±SD	SE	T value	P value
Extensive	57	4.68 ± 1.52	0.20	7.21	0.001
Mild/Moderate	63	6.85 ± 1.74	0.22		

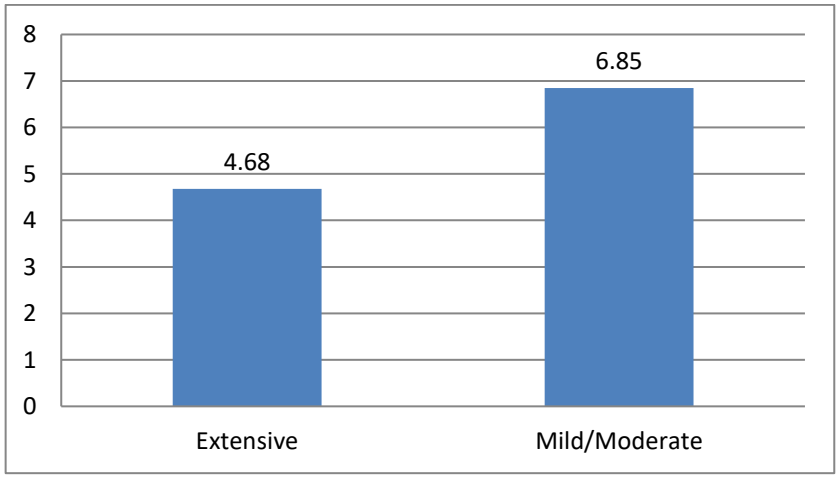

Figure 3: Comparison of Mean Residual Alveolar Bone Height in Extensive and Mild-to-Moderate Maxillary Sinus Pneumatization

Table 4 & Figure 4 compare the Schneiderian membrane thickness between maxillary sinuses with and without sinus septa. The mean membrane thickness in the septa-present group **(**n = 41**)** was 1.94 ± 0.63 mm, whereas the septa-absent group (n = 79) showed a lower mean thickness of 1.62 ± 0.58 mm. The corresponding standard errors (0.10 mm and 0.07 mm, respectively) indicate that the groups mean estimates were obtained with good precision. Analysis using the independent-samples Student's t-test revealed a statistically significant difference between the two groups (t = 2.71, p = 0.001). These findings demonstrate that the presence of maxillary sinus septa is associated with a significantly greater Schneiderian membrane thickness, highlighting a potential anatomical relationship that may be relevant during preoperative assessment and sinus floor elevation procedures.

Table 4: Membrane Thickness by Septa

Group	N	Mean ± SD	SE	T value	P value
Septa Present	41	1.94 ±0.63	0.10	2.71	0.001
Septa Absent	79	1.62 ±0.58	0.07		

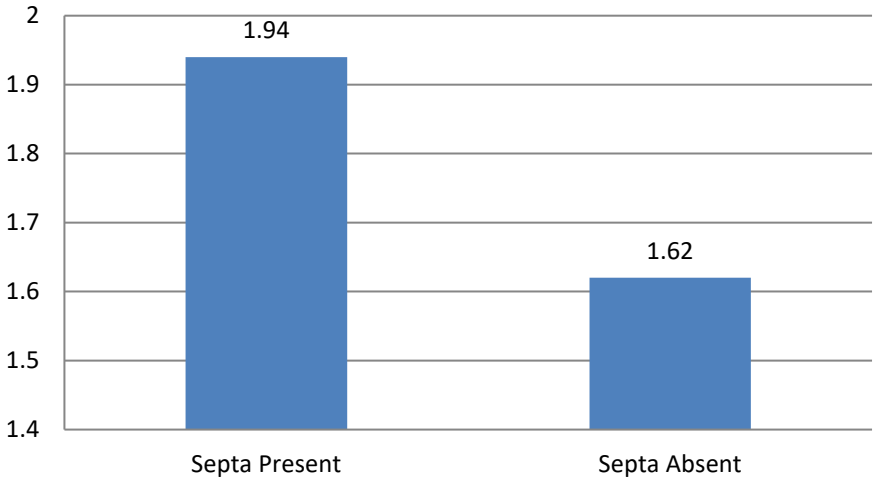

Figure 4: Comparison of Schneiderian Membrane Thickness Between Maxillary Sinuses with and without Septa

Table 5 & Figure 5 present the visibility of the PSAA in the evaluated maxillary sinuses. The PSAA was identified on CBCT images in 95 of the 120 sinuses (79.2%), while it was not detectable in 25 sinuses (20.8%). These findings indicate that the artery can be visualized radiographically in the majority of cases. The high detection rate underscores the value of CBCT in preoperative assessment, as accurate identification of the PSAA may assist clinicians in surgical planning and help reduce the risk of vascular complications during sinus floor elevation and other procedures involving the posterior maxilla.

Table 5: Visibility of PSAA

PSAA Visibility	Number of Sinuses (n)	Percentage (%)
Visible	95	79.2
Not Visible	25	20.8
Total	120	100.0

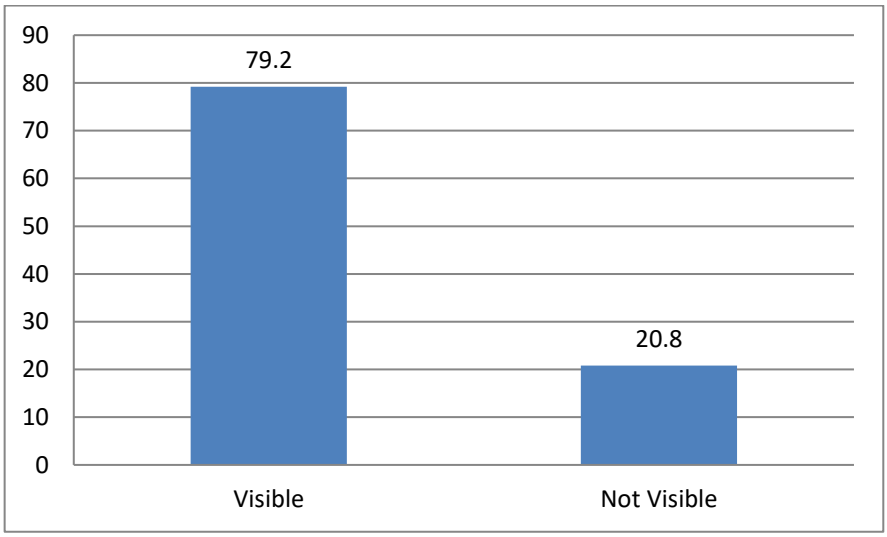

Figure 5: Distribution of PSAA Visibility on CBCT in the Evaluated Maxillary Sinuses

Table 6 summarizes the relationship between residual alveolar bone height and the degree of maxillary sinus pneumatization. Pearson's correlation analysis demonstrated a moderate negative correlation between these variables ($r = -0.58$), indicating that an increase in sinus pneumatization was associated with a reduction in residual alveolar bone height. This correlation was highly statistically significant ($p < 0.001$). Furthermore, the 95% CI (−0.70 to −0.43) excluded zero, supporting the strength and precision of the observed association. These results suggest that extensive maxillary sinus pneumatization is closely associated with diminished residual alveolar bone height, emphasizing its clinical relevance in preoperative implant assessment and the possible need for sinus floor augmentation to achieve adequate bone support.

Table 6: Correlation Between Residual Bone Height and Degree of Sinus Pneumatization

Variables Compared	Pearson's r	95% CI	P value	Interpretation
Residual bone height vs. sinus pneumatization	-0.58	-0.70 to -0.43	<0.001	Moderate negative correlation

Table 7 presents the findings of the binary logistic regression analysis performed to identify factors independently associated with reduced residual alveolar bone height. Extensive maxillary sinus pneumatization emerged as a significant independent predictor of reduced bone height. The positive regression coefficient ($\beta = 1.14$) indicates that extensive pneumatization increases the probability of reduced residual alveolar bone height. The odds ratio (OR = 3.12) shows that maxillary sinuses with extensive pneumatization were 3.12 times more likely to exhibit reduced residual bone height than those with mild to moderate pneumatization. This association was statistically significant (Wald $\chi^2 = 10.84$, $p = 0.001$). In addition, the 95% CI (1.61–6.05) did not cross 1.0, providing further evidence of the reliability and statistical significance of the observed association. These results indicate that extensive maxillary sinus pneumatization is an important independent predictor of reduced residual alveolar bone height and should be taken into account during preoperative evaluation and treatment planning for implant-supported rehabilitation in the posterior maxilla.

Table 7: Binary Logistic Regression Analysis for Factors Associated with Reduced Residual Bone Height

Predictor Variable	Regression Coefficient (β)	OR	95% CI	Wald χ^2	P value
Extensive sinus pneumatization	1.14	3.12	1.61–6.05	10.84	0.001

Discussion

Successful implant rehabilitation in the posterior maxilla depends largely on a comprehensive understanding of maxillary sinus anatomy. Anatomical variations such as reduced residual alveolar bone height, Schneiderian membrane thickening, sinus septa, sinus pneumatization, and the location of the PSAA may directly

influence the choice of sinus augmentation technique and the likelihood of surgical complications. Consequently, three-dimensional CBCT imaging has become an indispensable component of preoperative assessment because it provides precise visualization of these anatomical structures and supports evidence-based treatment planning.

In the present study, the mean residual alveolar bone height was 5.82 ± 2.04 mm, suggesting that many patients would require sinus floor elevation before implant placement. Limited vertical bone height in the posterior maxilla is commonly attributed to post-extraction alveolar ridge resorption together with progressive expansion of the maxillary sinus. Comparable observations have been described by Neugebauer et al. (2010) [13], who demonstrated that CBCT enables accurate measurement of available bone and assists clinicians in selecting the most appropriate sinus augmentation approach. Accurate determination of residual bone height is therefore essential for improving primary implant stability and minimizing surgical complications.

Evaluation of the Schneiderian membrane showed a mean thickness of 1.73 ± 0.61 mm, while mucosal thickening exceeding 2 mm was observed in 21.7% of the examined sinuses. Membrane thickness is an important consideration because inflammatory changes or excessive thickening may complicate membrane elevation and influence graft healing. Similar radiographic findings were reported by Bornstein et al. (2012) [14], who highlighted the accuracy of CBCT in assessing Schneiderian membrane morphology. Furthermore, the systematic review by Amid et al. (2021) [15] emphasized that pre-existing membrane thickening should be carefully evaluated before sinus augmentation, as it may increase the risk of postoperative complications and affect surgical outcomes.

Another important observation in this study was the presence of sinus septa in 34.2% of the evaluated maxillary sinuses, with the middle region representing the most frequent location. Sinus septa are clinically significant because they may interfere with membrane elevation, increase the difficulty of creating the lateral window, and predispose to membrane perforation. A similar prevalence and clinical significance have been described by Naitoh et al. (2009) [14], who reported that CBCT is highly effective in identifying the morphology and distribution of sinus septa before surgery. Recognition of these structures during treatment planning enables modification of the surgical technique and may reduce intraoperative complications.

The present investigation also demonstrated extensive sinus pneumatization in a substantial proportion of cases, with a significant association between increased pneumatization and reduced residual alveolar bone height.

Expansion of the maxillary sinus following tooth loss is one of the principal factors responsible for inadequate bone volume in the posterior maxilla. These findings support those of Neugebauer et al. (2010) [16], who emphasized the value of CBCT in accurately depicting sinus morphology and determining the necessity for sinus floor elevation during implant treatment planning. The PSAA was clearly visualized in 79.2% of the CBCT examinations. Identification of this artery is clinically relevant because accidental injury during preparation of the lateral bony window may result in excessive bleeding, impaired visibility, and prolonged surgical time. Preoperative recognition of its anatomical course allows clinicians to modify the osteotomy design and perform sinus augmentation procedures more safely.

Assessment of sinus health revealed mucosal thickening in a notable percentage of patients, highlighting the importance of identifying pre-existing sinus abnormalities before implant surgery. Maillet et al. (2011) [17] demonstrated that CBCT is highly sensitive in detecting inflammatory changes and pathological conditions affecting the maxillary sinus that may not be evident on conventional radiographs. More recently, Küçükkurt (2025) [18] reported a considerable prevalence of sinus pathologies

among dental implant candidates and emphasized the need to identify odontogenic factors before undertaking implant therapy. These findings reinforce the role of CBCT not only in anatomical assessment but also in evaluating sinus health before sinus augmentation.

Overall, the findings of the present study corroborate previous evidence demonstrating that CBCT provides comprehensive three-dimensional information regarding the maxillary sinus and surrounding anatomical structures. Detailed evaluation of residual alveolar bone height, Schneiderian membrane thickness, sinus septa, sinus pneumatization, vascular anatomy, and sinus pathology enables clinicians to formulate individualized surgical strategies, reduce the risk of intraoperative complications, and improve the predictability of sinus lift procedures. Routine incorporation of CBCT into preoperative implant assessment may therefore contribute to safer surgery and improved long-term outcomes for implant-supported rehabilitation in the posterior maxilla.

Limitations

The findings of this study should be interpreted in light of certain limitations. As the investigation was retrospective, the analysis relied exclusively on existing CBCT records, limiting the availability of detailed clinical and surgical information. Consequently, the influence of the observed anatomical variations on the actual outcomes and complications of sinus lift procedures could not be determined. Furthermore, the study was conducted using data from a single institution, which may restrict the applicability of the findings to broader populations. The evaluation was confined to radiographic observations, without confirmation through surgical findings or histopathological examination. In addition, patient-related variables such as age, sex, dental status, and systemic health were not investigated as potential factors affecting maxillary sinus anatomy. Future prospective, multicenter studies involving larger and more diverse populations, together with clinical validation of radiographic findings, are warranted to further clarify the impact of sinus anatomy on the safety and success of sinus augmentation procedures.

Conclusion

Comprehensive assessment of the maxillary sinus is a fundamental step in planning sinus floor elevation for implant rehabilitation in the posterior maxilla. CBCT provides precise three-dimensional visualization of the sinus and adjacent anatomical structures, allowing accurate identification of clinically important features such as residual alveolar bone height, Schneiderian membrane thickness, sinus septa, degree of pneumatization, and vascular anatomy. Recognition of these anatomical variations before surgery assists clinicians in selecting the most appropriate surgical approach, minimizing the likelihood of intraoperative complications, and improving treatment planning. Therefore, routine use of CBCT during preoperative evaluation can enhance the safety, predictability, and long-term success of implant-supported rehabilitation involving the posterior maxilla.

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