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ORIGINAL ARTICLE

Cone beam computed tomography evaluation of anatomic variations of the maxillary sinus and zygomatic bone to minimize the risk of sinus lift procedures

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ABSTRACT

Objectives: To detect anatomic variations in the maxillary sinus and zygomatic bone with respect to age and gender using cone beam computed tomography (CBCT), to minimize procedural risks during sinus lift surgery and optimize implant planning.

Methods: This cross-sectional prevalence study analyzed 98 CBCT scans (49 patients, aged 18-60 years) referred to Kunhitharuvai Memorial Charitable Trust (KMCT) Dental College, Kerala, South India, from December 2017 to December 2019. Multi-planar images were assessed for septa (presence, morphology, location), maxillary sinus pneumatization (MSP), and zygomatic bone pneumatization (ZBP). Associations with age and gender were evaluated.

Results: Septa were identified in 35/98 (35.7%) cases, with the highest prevalence in the 51-60 year group [21/35 (60.0%)], most frequently located in the middle region [13/35 (37.1%)]. Complete septa [8/35 (22.9%)] increased with age. MSP was observed in 63/98 cases (64.3%), most frequent in the 51-60 year group [31/63 (49.2%)]. ZBP occurred in 10/98 cases (10.2%), most commonly in the 41–50 year group [5/10 (50.0%)], with all cases showing a multilocular pattern. No significant gender differences were detected for septa, MSP, or ZBP ($p>0.05$).

Conclusion: Maxillary sinus septa and pneumatization patterns are age-dependent, with septa prevalence and completeness increasing with age. ZBP was less frequent but demonstrated a distinct multilocular pattern. Recognition of these variations is crucial for safe sinus lift procedures and effective implant treatment planning.

Keywords: Cone-Beam Computed Tomography (MeSH); Maxillary Sinus (MeSH); Maxillary Sinus Septa (Non-MeSH); Maxillary Sinus Pneumatization (MeSH); Zygomatic Bone Pneumatization (Non-MeSH); Sex Characteristics (MeSH).

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INTRODUCTION

The maxillary sinus is a pyramidal cavity, with its base located along the lateral nasal wall and the apex extending toward the zygomatic process of the maxilla.[1] Anatomical variations, including pneumatization and the presence of antral septa, are frequently observed. A thorough understanding of maxillary sinus anatomy and its possible variations is essential for surgical interventions in the posterior maxillary region.[2] Maxillary sinus septa are cortical bony partitions within the sinus wall, and their removal is often required prior to sinus augmentation for dental implant placement. Their presence increases the risk of Schneiderian membrane perforation, which may subsequently lead to maxillary sinusitis and, ultimately, implant failure.[3] Another major challenge in implant-supported rehabilitation is maxillary sinus pneumatization (MSP). Various grafting techniques, including sinus lifting and autogenous onlay bone grafts, have been proposed to restore the architecture of the atrophic maxilla, thereby facilitating implant placement in resorbed sites. Furthermore, full-arch reconstructions using autogenous bone grafting frequently necessitate an extraoral donor site, which not only increases patient morbidity but also prolongs the treatment period before definitive fixed prostheses can be delivered.[4]

An alternative to extensive reconstructive procedures for managing maxillary sinus pneumatization and antral septa is the placement of zygomatic implants. Stella and Warner[5] introduced a simplified technique for extra-sinus zygomatic implant placement that eliminates the need for antrostomy and sinus membrane elevation, thereby streamlining the surgical procedure and enhancing prosthetic outcomes. Nonetheless, the presence of zygomatic bone pneumatization poses a risk of implant failure, highlighting the importance of thorough radiological evaluation of the zygomatic bone prior to implant placement. Most existing studies focus on sinus septa or pneumatization alone, with limited evidence on concurrent variations of the maxillary sinus and zygomatic bone across age and gender; this gap hampers strategic, patient-specific implant planning.

This knowledge gap limits the development of patient-specific, strategic approaches to implant rehabilitation. Therefore, the aim of this study was to evaluate the anatomic variations of the

maxillary sinus and zygomatic bone to support more effective and individualized implant treatment planning.

METHODS

This cross-sectional prevalence study analyzed 98 randomly selected CBCT projection datasets from 49 patients at Kunhitharuvai Memorial Charitable Trust (KMCT) Dental College, Kerala University of Health Sciences, South India, between December 2017 and December 2019. Demographic variables, including age and gender, were retrieved from the CBCT software records prior to image evaluation. All study procedures complied with the ethical principles of the Helsinki Declaration (2013), and the study protocol was approved by the Institutional Review Board (IRB No. KMCT DC/IEC/2017/26).

Patients aged 18-60 years who required CBCT imaging of the maxilla for implant assessment or other diagnostic purposes were included in the study. Exclusion criteria comprised systemic bone-related diseases, pathological growths involving the maxillary sinus or zygomatic bone, maxillary sinusitis, prior trauma or surgical manipulation of the oral and maxillofacial region, and CBCT images with motion artefacts.

CBCT scans were obtained using an i-CAT 17-19 Next Generation unit (Imaging Sciences International, LLC, Hatfield, PA, USA) with exposure parameters of 120 kVp, 3-7 mAs, voxel size 200-300 µm, field of view 16×13 cm, and scan time of 8-14 seconds. Image analysis was performed with Anatomage InVivo 5 software, version 5.3 (InVivo Dental; Anatomage, San Jose, CA, USA).

The CBCT datasets were evaluated in coronal, axial, and sagittal sections to determine the prevalence (Figure 1, 2), location, and morphology of septa. Septa measuring more than 2 mm in height-considered a significant impediment to sinus floor elevation-were recorded and categorized by location as anterior, middle, or posterior. In edentulous patients, a tangent drawn to the nasal cavity floor (NCF) served as the reference line, and the distance from this line to a tangent

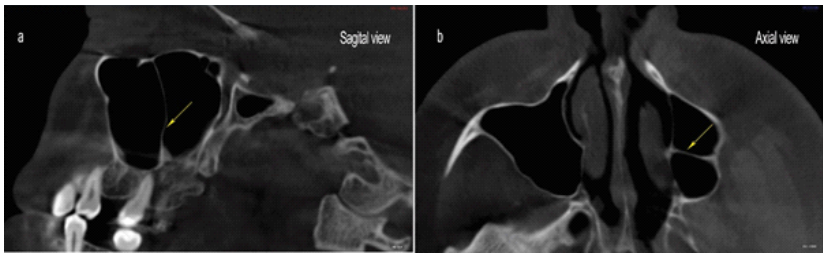


Figure 1: Complete septa

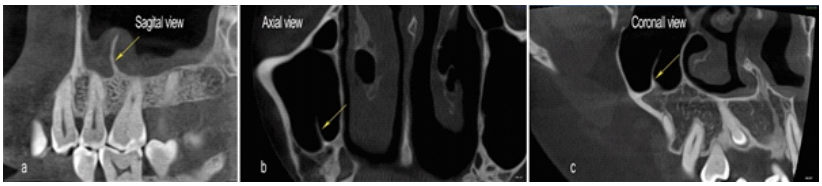
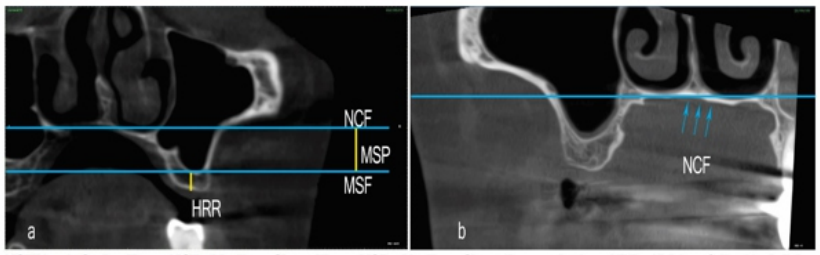


Figure 2: Incomplete septa



NFC:Nasal Cavity Floor, MSF: Maxillary Sinus Floor, Maxillary Sinus Pneumatization, HRR: Height of Residual Rdge

Figure 3: MSP in edentulous area

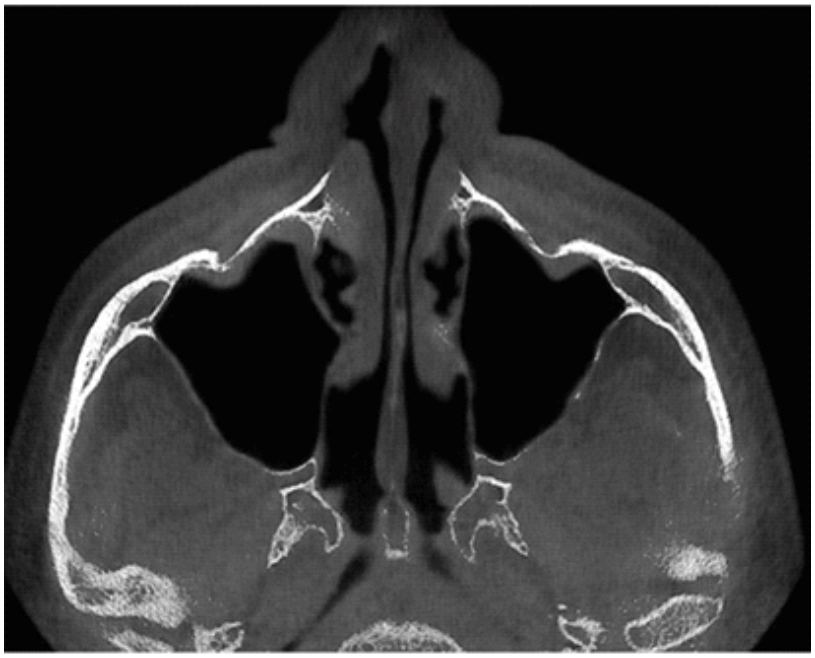


Figure 4: Zygomatic bone pneumatization

drawn along the maxillary sinus floor (MSF) was measured to assess maxillary sinus pneumatization (MSP). The distance from the MSF tangent to the height of the residual ridge (HRR) was additionally recorded to determine the remaining bone height (Figure 3). In dentate patients, an imaginary line passing through the apices of the maxillary posterior teeth was used as a reference, and pneumatization was assessed according to the coronal position of the maxillary sinus floor relative to this line. Zygomatic bone

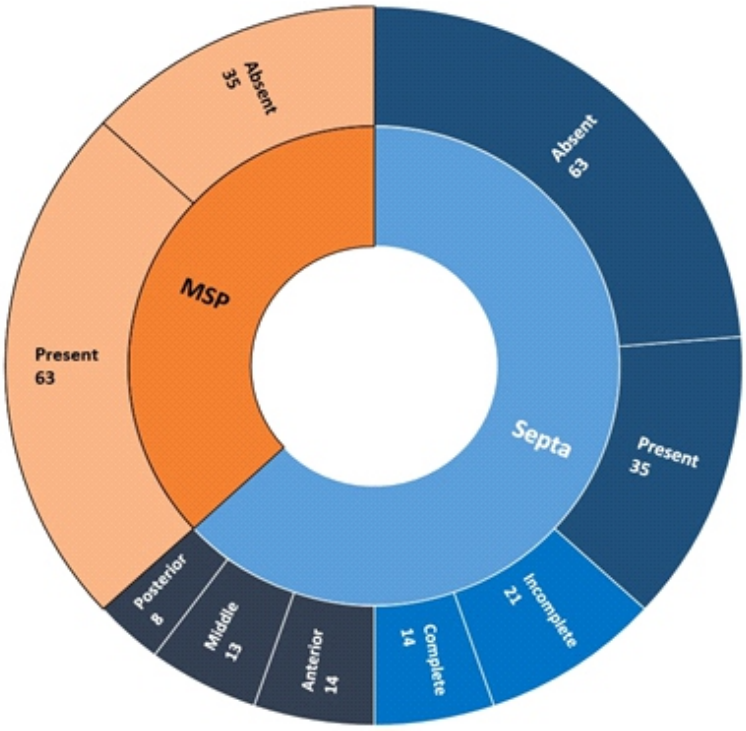


Figure 5: Sunburst image showing the septa and maxillary sinus pneumatization (MSP)

pneumatization (ZBP) was assessed using an approach similar to that described by Nascimento HAR, et al.[6] Hypodense defects resembling mastoid air cells were considered indicative of pneumatization and were classified as unilocular when a single, well-defined oval hypodense defect was present, or multilocular when multiple small hypodense cavities were observed (Figure 4).

RESULTS

Results were stratified by age and gender. Septa were most frequently observed in the 51-60 year age group, predominantly located in the middle region. The prevalence of complete septa also showed a gradual increase with advancing age. Maxillary sinus pneumatization (MSP) was most common in the 51-60 year group, whereas zygomatic bone pneumatization (ZBP) was most prevalent in the 41-50 year group, with the multilocular pattern being the most frequently observed. No significant gender-related differences were observed in the prevalence of septa or in the pneumatization of the maxillary sinus and zygomatic bone. The sunburst diagram (Figure 5) illustrates 12 cases (30.0%) with incomplete septa and 7 cases (17.5%) with complete septa. The detailed distribution of patients by age, gender, septa presence, and pneumatization patterns of the maxillary sinus and zygomatic bone is presented in Tables I and II.

DISCUSSION

This study assessed anatomic variations of the maxillary sinus and zygomatic bone using CBCT, emphasizing their relevance in implant treatment planning. Septa were most common in the 51-60 year age group, maxillary sinus pneumatization was frequent in older patients, and zygomatic bone pneumatization was observed mainly in the 41-50 year group with a multilocular pattern. No significant gender differences were noted, highlighting age as the primary determinant of variation.

Several studies have reported wide variations in the prevalence of maxillary sinus septa, ranging from 16% to 67%, with the highest occurrence typically observed in the region of the first and second molars.[7-11] These findings are consistent with the results of the present study. Krennmair G, et al.[12] also reported a significantly higher incidence of septa in edentulous ridges, which aligns with our observations, although in this study dentulous and edentulous patients were not analyzed separately. Takeda G, et al.[13] further emphasized that the prevalence of septa is a critical factor to consider in planning implant procedures.

Most studies evaluating septa location have reported a predominance in the middle region of the maxillary sinus.[1,14,15] Other studies, however, there could be alternative regional patterns. In the present study, septa were most frequently observed in the anterior (40%) and middle (37.1%) regions. These variations across studies may be attributed to differences in data collection methods and the absence of standardized criteria for defining septa location.

Alveolar pneumatization has been reported in 100% of patients by Lana JP, et al. (2012), [2], 47.6% by Kocak N, et al., (2019)[14], 57.5% by Shahidi S, et al. (2016),[16] and 54% by Cavalcanti MC, et al. (2018).[17] In the present study, it was observed in 63 sinuses (64.3%), underscoring the clinical relevance of sinus lift surgery as a viable solution.

The present study demonstrated that maxillary sinus pneumatization increases with age and may vary by tooth region across different age groups. Jun et al.[18] similarly reported significant age-related differences in sinus volume, reinforcing the need for sinus lift procedures in implant rehabilitation.

The present study found no gender-related differences in maxillary sinus pneumatization, consistent with previous reports showing no variation in sinus volume after the third decade of life and no significant differences in sinus depth between males and females.[19] The posterior maxilla is often associated with reduced implant success rates due to poor bone quality and significant alveolar ridge resorption, particularly following tooth loss. As a result, sinus elevation with bone grafting has become a widely adopted technique in clinical practice. However, this

Table I: Association between age and prevalence of septa, maxillary sinus pneumatization (MSP) and zygomatic bone pneumatization n=49 (ZBP)

Age Group	Number (%)	Prevalence of septa (%)	Morphology of Septa		Location of septa			Prevalence of MSP (%)	Prevalence of ZBP (%)	Pattern of ZBP	
			Complete (%)	Incomplete (%)	Anterior (%)	Middle (%)	Posterior (%)			Unilocular	Multilocular
18-30	31 (31.6)	5 (16.7)	2 (6.7)	3 (10)	1 (3.2)	1 (3.2)	3 (9.7)	9 (14.3)	1 (10)	0	1
31-40	13 (13.5)	4 (30.8)	1 (7.7)	3 (23.1)	3 (23.1	1 (7.7)	0	11 (17.5)	2 (20)	0	2
41-50	19 (19.4)	5 (26.9)	3 (15.8)	2 (11.1)	4 (21.1)	1 (5.2)	0	12 (19)	5 (50)	0	5
51-60	35 (36.5)	21 (60)	8 (22.9)	13 (37.1)	6 (17.1)	10 (28.6)	5 (14.3)	31 (49.2)	2 (20)	0	2
Total	98	35	14	21	14	13	8	63	10 (10.2)	0	10
p-value	–	–	0.01*		0.005*			<0.001**	0.04*		

Table II: Association between gender and prevalence of septa, maxillary sinus pneumatization (MSP) and zygomatic bone pneumatization n=49 (ZBP)

Gender	Number (%)	Prevalence of septa (%)	Morphology of Septa		Location of septa			Prevalence of MSP (%)	Prevalence of ZBP (%)	Pattern of ZBP	
			Complete (%)	Incomplete (%)	Anterior (%)	Middle (%)	Posterior (%)			Unilocular	Multilocular
Male	20 (40.8)	19 (37.5)	7(17.5)	12(30.0)	9(22.5)	7(17.5)	3(7.5)	29(72.5)	15 (50)	0	5
Female	29 (59.2)	16 (27.6)	7(12.1)	9(15.5)	5(8.6)	6(10.3)	5(8.6)	34(58.6)	5 (50)	0	5
Total	49	35	14	21	14	13	8	63	10	0	10
p-value	–	–	0.14		0.13			0.11	0.38		

procedure carries the risk of various intraoperative and postoperative complications, including membrane perforation, wound dehiscence, severe swelling, hematoma, ecchymosis, maxillary sinusitis, epistaxis, local infection, and upper lip paresthesia, as reported by Kim YK,et al.,[20] Brånemark first introduced the concept of zygomatic implants in 1988 as an alternative treatment for patients with unfavorable maxillary sinus anatomy. Although their placement is generally not associated with major complications such as rhinosinusitis, intra-sinus zygomatic implants have been reported to cause asymptomatic radiologic alterations of the maxillary sinus in a considerable number of patients.[21] Hence, careful assessment of maxillary sinus homeostasis, both preoperatively and postoperatively, is essential. Several studies evaluating the clinical outcomes of extra-sinus zygomatic implants, placed laterally to the maxillary sinus, have demonstrated high survival rates, supporting their role as a reliable alternative.[4,22] Furthermore, a systematic review by Tuminelli FJ, et al.,[23] highlighted the additional advantage of immediate loading, further enhancing their clinical utility.

Nascimento HAR, et al., (2015) reported a low prevalence of zygomatic bone pneumatization (3.3%) with no significant correlation to age or gender.[6] However, few subsequent studies have addressed this finding. Given the clinical relevance of the zygomatic bone, the present study identified a higher prevalence of pneumatization (10.2%), further supporting the role of zygomatic implants as an alternative when sinus lift surgery is contraindicated. Another potential option to avoid sinus lift procedures is the use of a complete septum of sufficient thickness for implant placement. In 2017, Dragan E, et al. [24] proposed that the sinus septum itself could serve as an alternative site for implant placement within the maxillary sinus.

In the present study, incomplete septa (60%) were more prevalent than complete septa (40%). However, most previous studies have reported contrasting findings, which may reflect population-related differences. The clinical significance of partial and complete septa is determined by their location, height, and the surgical procedure undertaken. CBCT is a valuable tool for detailed evaluation of maxillary sinus and zygomatic bone anatomy, thereby reducing surgical risks.[24] The clinical significance of the present findings lies in providing anatomical data that support the use of extra-sinus zygomatic implants as an alternative to sinus floor elevation. Such information can be incorporated into the decision-making process for guided implant placement in the posterior maxilla and zygomatic region.[25]

This study has several limitations, including its retrospective design and uneven sample distribution with respect to patients' dental status. As a result, important clinical details, such as the cause of tooth loss, sinus volume, extent of surgical trauma during extraction, duration of edentulousness, and the relationship between the maxillary sinus floor and root apex prior to extraction, could not be assessed. In addition, correlating zygomatic bone pneumatization with the presence of air cells was not feasible, as CBCT systems may not reliably represent Hounsfield units (HU), preventing confirmation that the observed hypodense areas indeed contained air. Therefore, further prospective studies are required to address these limitations and to better establish the surgical role of extra-sinus zygomatic implants as an alternative for posterior maxillary rehabilitation.

CONCLUSION

In this study demonstrated that gender had negligible influence on maxillary sinus variations, whereas the prevalence of septa and pneumatization increased with age. These findings highlight the importance of preoperative three-dimensional imaging to detect antral septa and pneumatization, thereby reducing surgical risks. Additionally, evaluating zygomatic bone pneumatization in three dimensions may guide oral and maxillofacial radiologists and implantologists in considering alternative implant strategies to avoid sinus lift procedures. However, further prospective studies are needed to validate these observations.

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AUTHORS' CONTRIBUTION

The Following authors have made substantial contributions to the manuscript as under:

NU & PS: Acquisition, analysis and interpretation of data, drafting the manuscript, approval of the final version to be published

AMK, MV & AA: Conception and study design, analysis and interpretation of data, critical review, approval of the final version to be published

RP: Analysis and interpretation of data, drafting the manuscript, approval of the final version to be published

Authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICT OF INTEREST

Authors declared no conflict of interest, whether financial or otherwise, that could influence the integrity, objectivity, or validity of their research work.

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DATA SHARING STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request

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