Original Article

CONE-BEAM COMPUTED TOMOGRAPHIC EVALUATION OF MAXILLARY SINUS ANATOMY AND SEPTAL VARIATIONS: CLINICAL IMPLICATIONS FOR SURGICAL SAFETY

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ABSTRACT

Comprehending the architecture of maxillary sinus and its septa is crucial for preventing complications during maxillofacial procedures, as it guides clinicians in selecting optimal surgical techniques. This study used cone-beam computed tomography (CBCT) to examine anatomical variations of maxillary sinus and its septa. CBCT scans of 500 dentate patients aged 25–65 years who underwent head and neck imaging at Department of Radiology, Saveetha Dental College and Hospitals, Chennai, India, between January and June 2024 were analyzed. Measurements included maxillary sinus dimensions, lateral wall thickness, septa prevalence and location, septa orientation, and perforation risk on both sides. Independent t-test was used to compare differences between the right and left sinuses. The mean maxillary sinus width was 23.20 ± 4.22 mm on the right and 23.73 ± 4.62 mm on the left ($p=0.705$); depth was 33.39 ± 3.53 mm on the right and 34.57 ± 3.27 mm on the left ($p=0.280$); and height was 34.44 ± 2.44 mm on the right and 35.16 ± 2.24 mm on the left ($p=0.282$), none showing significant differences. The lateral wall thickness at 3 mm measured 2.10 ± 1.20 mm on the left and 2.40 ± 1.31 mm on the right ($p=0.457$). Most septa were located in the middle region with mediolateral orientation, and moderate perforation risk predominated. The results demonstrated no significant bilateral variation in maxillary sinus dimensions, with average wall thickness ranging between 2–3 mm. Routine assessment of sinus anatomy and septa is essential to reduce surgical risks and enhance treatment outcomes.

Key words: Maxillary sinus, Maxillary sinus septa, Imaging, Surgical anatomy.

Introduction

The maxillary sinuses are an essential component of the paranasal sinuses and have a major architectural significance in the human skull. These paired, cavernous chambers are situated within the maxillary bones, adjacent to the nose, contributing significantly to the cheek's prominence. Lined by the delicate Schneiderian membrane, the sinuses play a vital role in maintaining health and function [1, 2]. As some of the largest paranasal air-filled cavities, they are strategically located within the maxillary body on either side of the face, supporting the overall craniofacial balance [3]. The pinnacle of the maxillary sinus extends into the maxilla's zygomatic process, while the base rests upon the lower lateral nasal wall. This irregular three-sided pyramid shape is its defining feature. This anatomical positioning places the sinuses directly above the upper molars and premolars, establishing a close relationship with these dental structures. Although individual variances are frequent, typical measurements from earlier research show that the sinus height averages 3.5 cm, width 2.5 cm, and depth 3.25 cm [4, 5]. Furthermore, the sinus cavity is frequently divided into compartments by the maxillary sinus septa, which are tiny bony barriers. These septa can vary in size, direction, and number, commonly occurring in the posterior region near the premolars and molars, and are present in 20% to 58% of individuals [6, 7].

As early as the tenth week of intrauterine life, the maxillary sinuses begin to form, making them the first paranasal sinuses to mature. This first stage produces a cavity filled with fluid that expands until birth, reaching a volume of roughly 6–8 cm³. Postnatally, their development occurs in distinct phases: first, a robust transverse expansion until age three, followed by critical vertical growth between ages seven and twelve, during which the sinuses extend toward key anatomical landmarks like the nostrils, nasolacrimal duct, and zygomatic recess. After this dynamic growth period, the sinuses gradually mature in volume and complexity between the ages of twenty and thirty [8]. A key aspect of maxillary sinus development is pneumatization, a continuous physiological process in which air gradually replaces the initial fluid. Inferomedially into the hard palate, laterally into the zygomatic bone, and posteriorly into the ethmoid bones, this process increases the sinus's anatomical complexity [9].

When it comes to maxillofacial treatments, especially those involving dental implants, sinus lifts, and sinus augmentations, the structure of the maxillary sinus and its septa is extremely important [10]. The maxillary sinuses, being situated above the upper molars and premolars, often overlap with regions where dental implants are intended to be placed. Consequently, a thorough understanding of the relationship between these sinuses and dental implantology is essential for successful outcomes. The primary challenge in implant placement within the maxillary posterior region stems from the limited bone height available between the oral cavity and the floor of the maxillary sinus. Tooth loss, particularly in the molar region, leads to a gradual resorption of the alveolar bone. Over time, this bone resorption, combined with sinus pneumatization, reduces the available vertical bone height necessary for securing an implant. Placing an implant when there is not enough bone left runs the danger of puncturing the sinus membrane, which can result in problems like sinusitis or infection [11].

Cone-beam computed tomography (CBCT) has established itself as an effective three-dimensional imaging modality. Since its inception in 1982, it has become an essential diagnostic tool, renowned for producing high-resolution images that are free from the superimposition of surrounding anatomical structures [12, 13]. Compared to panoramic radiographs, CBCT offers superior visualization of anatomical details, making it invaluable in various clinical settings. Additionally, CBCT requires minimal scanning time while delivering critical information across multiple planes, all while maintaining a low radiation dose [14].

Given these advantages, the primary objective of this study was to examine the structural variations of the maxillary sinus and its septa using CBCT.

Materials and Methods

This study included a total of 500 patients aged between 25 and 65 years. Participants were dentate adults referred for a head and neck CBCT scan to the Department of Radiology at Saveetha Dental College and Hospitals, Chennai, India, between January and June 2024. The research was conducted in accordance with the 1975 Helsinki Declaration, as amended in 2013, and received approval from the Institutional Ethical Committee of Saveetha Dental College and Hospitals (IHEC/SDC/MSIMPLANT-2303/24/038). Informed consent was obtained from all participants. The sample size was calculated using G*Power Software, Version 3.0, based on mean and standard deviation values from a previous study [15], with a target sample size of 500 subjects at 80% power and an α level of 0.05 [16-20].

This study included patients aged 25 to 65 years, comprising both males and females, who met specific inclusion criteria: they were free of any periodontal diseases, had CBCT images demonstrating complete maxillary sinuses, and exhibited no missing teeth in the maxillary posterior region. Additionally, participants had not undergone any previous surgeries in the maxillary sinus area, and no artifacts were present in the maxillary sinus region. Patients with facial deformities, facial injuries, tumors, or other pathologies affecting the maxillary sinuses were excluded from the study.

The dimensions of the maxillary sinus, the thickness of its walls, the prevalence, location, and orientation of the maxillary sinus septa, as well as the potential risk of septal perforation, were meticulously assessed using Cone Beam Computed Tomography (CBCT) via the Sirona Orthophos XG XD system (NC, USA). A single investigator (RP) conducted all measurements bilaterally, ensuring uniformity across both the right and left sides for every participant included in the study.

Dimensions of maxillary sinus

The CBCT scan's coronal view between the sinus's medial wall and its lateral wall's outermost point was used to calculate the maximum width **(Figure 1)**. The maximum height was determined by measuring the coronal view of the CT scan between the sinus floor's lowest point and the sinus roof's highest point **(Figure 1)**. Using the CBCT's sagittal view between the sinus's most anterior and posterior points, the maximum depth was determined **(Figure 2)**.

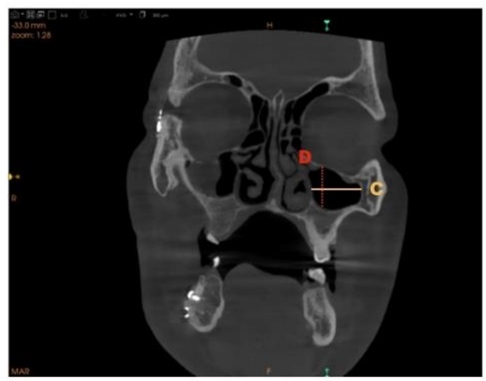

Figure 1. Assessment of maxillary sinus width (C) and height (D)

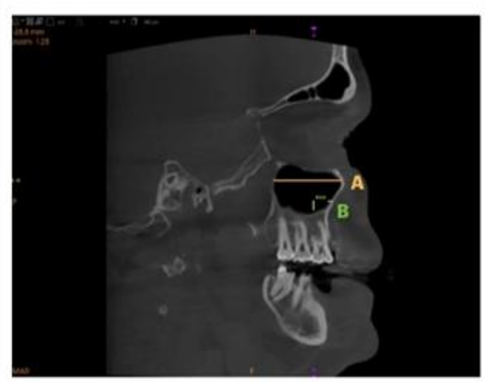

Figure 2. Assessment of maxillary sinus depth (A) and lateral wall thickness at 3mm (B)

Wall thickness

At a height of 3 mm, the maxillary sinus's lateral wall was measured for wall thickness **(Figure 2)**.

Prevalence and location of maxillary sinus septa
The presence or absence of sinus septa in the sinus cavities was referred to as maxillary sinus septa predominance. Furthermore, the placement was noted as anterior (mesial to the second premolar), middle (distal to the second premolar and mesial to the second molar), and posterior (distal to the second molar) **(Figure 3)**.

Orientation of maxillary sinus septa
The orientation of the septa in the patients was categorized into mediolateral, sagittal, and transverse orientations. The mediolateral septa were those aligned in a mediolateral direction, while the sagittal septa followed a path parallel to the sagittal plane. The transverse septa, on the other hand, were classified based on their orientation parallel to the sinus floor **(Figure 3)**.

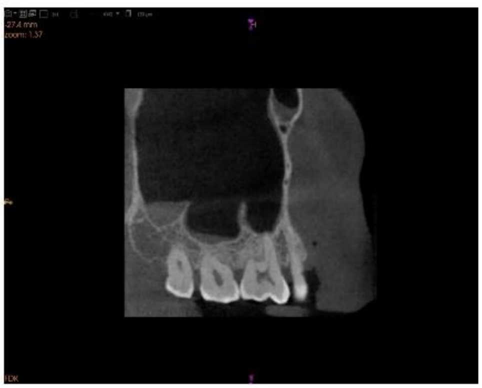

Figure 3. Assessment of prevalence, location and orientation of maxillary sinus septa

Perforation risk
Changed the maxillary sinus septa's perforation risk was evaluated using Al-Faraje's classification [21]. Based on the classification:

- Class I: Low-risk, one basal perpendicular septum
- Class II: Low-risk multiple basal perpendicular septa (two or more)
- Class III: One lengthy partial perpendicular septum that extends beyond the sinus base (moderate risk)
- Class IV: Two or more lengthy, partly perpendicular septa that extend beyond the sinus base (high risk)
- Class V: Low-risk partial horizontal septum
- Class VI: The sinus is divided into two distinct anatomical canals by a complete vertical septum (low risk).
- Complete horizontal septum positioned inferiorly (moderate risk) in Class VII div I
- Class VII div II: Full horizontal septum positioned above (minimal risk)

Statistical analysis
The Statistical Package for Social Sciences (SPSS Software, Version 23.0; IBM Corp., Armonk, NY, USA) was used to analyze the data. The results were evaluated using the Kolmogorov-Smirnov test and the Shapiro-Wilk test of normality. The data showed that the results had a parametric distribution. The data was presented using the mean and standard deviations. An independent t-test was used to examine the variations between the left and right sides. If the p-value was less than 0.05, the findings were considered statistically significant.

Results and Discussion

Demographic data
There were 279 men and 221 women among the 500 study participants. The mean age of the male and female participants was 52.6 and 53.2 years, respectively.

Dimensions of maxillary sinus
The maxillary sinus's average maximum width was found to be 23.20 ± 4.22 mm on the right side and 23.73 ± 4.62 mm on the left, with a p-value of 0.705, indicating no statistical significance. With a mean of 33.39 ± 3.53 mm on the right side and 34.57 ± 3.27 mm on the left, the maximum depth was likewise not statistically significant, with a p-value of 0.280. The mean maximal height of the maxillary sinus was 35.16 ± 2.24 mm on the left and 34.44 ± 2.44 mm on the right, with a p-value of 0.282, suggesting no statistically significant difference **(Table 1)**.

Table 1. Comparison of right and left maxillary sinus dimensions

	Maxillary Sinus Width (mm)	**Maxillary Sinus Depth (mm)**	**Maxillary Sinus Height (mm)**	**Wall Thickness (mm)**
Right	23.20 ± 4.22	33.39 ± 3.53	34.44 ± 2.44	2.40 ± 1.31
Left	23.73 ± 4.62	34.57 ± 3.27	35.16 ± 2.24	2.10 ± 1.20
p value*	0.705	0.280	0.282	0.457

*Independent t-test

Wall thickness
At a height of 3 mm, the average lateral wall thickness was 2.40 ± 1.31 mm on the maxillary sinus's right side and 2.10 ± 1.20 mm on its left. The significance value was 0.457, meaning there was no statistical significance **(Table 1)**.

Prevalence and location of maxillary sinus septa
Out of 500 individuals in the study, 271 participants (54.2%) were found to lack any septum, while 229 participants (45.8%) exhibited at least one septum. Among those with a septum, 81 individuals (35.4%) presented septa on the right side, 59 individuals (25.7%) on the left side, and 89 individuals (38.9%) had septa on both sides. Regarding the location of the maxillary sinus septa, the majority of patients had a septum that was most frequently found in the maxillary sinus's center, which was observed in about 58.9%

of instances on the right side and 61.5% of cases on the left. A lower proportion of patients had septa in the anterior region, with 27.1% on the right side and 24.7% on the left. Meanwhile, septa in the posterior region were seen in 14% of patients on the right side and 13.8% on the left side of the maxillary sinus [22-26].

Orientation of maxillary sinus septa

The most common orientation of the septa was mediolateral, which was seen in roughly 59.6% of instances on the right side and 61.2% on the left side of the maxillary sinus. Other orientations included sagittal, observed in 21.8% on the right and 22.4% on the left, and transverse septa, which appeared in 18.6% on the right and 16.4% on the left, both exhibiting comparatively lower frequencies than the mediolateral orientation.

Perforation risk

As per Al-Faraje's classification regarding the perforation risk associated with maxillary sinus septa, the distribution of risk levels was observed as follows: a low risk of perforation was present in approximately 30.4% of cases on the right side of the maxillary sinus and 31.2% on the left side. Moderate risk was notably higher, with 62.3% on the right and 64.6% on the left, exceeding the proportions observed for both low and high-risk categories [27-30]. In contrast, the high-risk category accounted for 7.3% on the right side and 4.2% on the left, with these assessments based on factors such as the number of septa, and their orientation within the maxillary sinus.

The assessment of the maxillary sinus is crucial for successful implant placement, especially in the posterior maxilla where limited bone height often complicates surgery. Continuous advancements in implant materials, surface modifications, and biomaterial [31-33]. Innovations, and optimized surface microgeometry have significantly enhanced implant biocompatibility and clinical outcomes [34-39]. Furthermore, patient-related variables such as age, gender, and implant site selection, along with refined surgical protocols, play an equally vital role in long-term success [40, 41]. Despite these advancements, accurate anatomical evaluation remains paramount. CBCT offers detailed three-dimensional visualization of the maxillary sinus and adjacent structures, allowing precise assessment of sinus floor proximity, membrane thickness, and septal variations. Hence, the present study utilized CBCT to investigate maxillary sinus anatomy and septal patterns in a South Indian population, contributing to safer and more predictable implant placement.

When comparing the right and left sides of the maxillary sinus, the mean depth, height, and width were not statistically significant. In order to comprehend the differences and similarities in sinus morphology, Muthukumaravel N *et al*. [42] conducted a thorough analysis of the maxillary sinus dimensions in the South Indian population. Their study carefully assessed the maxillary sinus's height, width, and depth; the average values fell within a range strikingly comparable to those found in the current analysis. This similarity in sinus dimensions suggests that anatomical features may be shaped by genetic or evolutionary factors that remain consistent within the same population. In a detailed exploration of maxillary sinus height, Uthman A *et al*. [43] conducted an investigation focused on the Iraqi population. Their meticulous analysis revealed distinct measurements of sinus height, shedding light on anatomical variations within this specific demographic. When these findings are juxtaposed with a corresponding study conducted on the South Indian population, a marked and statistically significant divergence in mean ranges becomes apparent.

Additionally, the thickness of the sinus wall, measured at a height of 3 mm, fell within the range of 2-3 mm in the present study. This range aligns with findings from studies conducted by Danesh-Sani SA *et al*. [44] and Yang HM *et al*. [45]. Regarding the location of the maxillary sinus septa, most individuals had a septum that was typically found in the middle of the sinus. This was evident in roughly 58.9% of cases on the right and 61.5% of cases on the left. The mediolateral orientation of the septa was the most common, occurring in approximately 59.6% of cases on the right side of the maxillary sinus and 61.2% on the left. In a retrospective analysis, Alhumaidan G *et al*. [46] reported that the majority of the septa were located in the middle, followed by anterior and posterior, which is similar to the current study. Furthermore, septa were more prevalent in the middle section than in the anterior and posterior portions, and they were more often oriented mediolaterally, according to Sakhdari S *et al*. [47]. In alignment with our findings, Schiller LA *et al*. [48] and Kocak N *et al*. [49] also observed that septa were predominantly oriented in the mediolateral direction. Septa with a sagittal orientation were less commonly identified, while those with a transverse orientation were noted to be even rarer.

Moreover, the present study undertook an evaluation of the perforation risk linked to the presence of maxillary sinus septa. Assessing the perforation risk associated with maxillary sinus septa is crucial, particularly in procedures like sinus augmentation or dental implant placement. Identifying whether the risk of perforation is low, moderate, or high enables surgeons to adapt their techniques, employ more cautious approaches, or even modify treatment plans to reduce the likelihood of membrane damage [50-53]. It was observed in the present study that the incidence of moderate risk stood out as the most prevalent, followed by cases of low and high risk. A similar study employing CBCT analysis revealed a comparable distribution, with moderate perforation risk observed in 60.4% of cases, low risk in 30.8%, and high risk in 8.8%. In contrast, Sigaroudi AK *et al*. [54] reported a lower perforation risk, identifying that 68% of their subjects exhibited a low risk, while the remaining 32% were classified as having a moderate to high risk.

The present study, while offering valuable insights, is not without its limitations. One notable limitation is the absence of gender-based comparisons, which could have provided a deeper understanding of potential anatomical differences between male and female participants. Additionally, this study focused solely on individuals with dentate conditions, excluding those who are partially dentate or completely edentulous. As a result, the impact of tooth loss on the morphology of the maxillary sinus and septa remains unexplored. Future studies are necessary to investigate these variations in populations with different dental statuses, particularly in relation to how tooth loss might influence sinus and septa anatomy.

Despite these limitations, the current study contributes significantly to our understanding of maxillary sinus and septa variations within the South Indian population. This knowledge is particularly beneficial for clinicians, as it aids in the careful selection of surgical techniques, helping to prevent complications during procedures. The findings of this study serve as a foundational guide for more precise and effective treatment planning in clinical practice [55-58].

Conclusion

In conclusion, there was no statistically significant difference between the left and right sides of the maxillary sinus in terms of mean depth, height, or width. The sinus wall thickness ranged from 2 to 3 mm at a height of 3 mm. Most people had septa that were mostly found in the center of the maxillary sinus; the most common orientation was mediolateral. The most common perforation risk was moderate.

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Conflict of interest: None

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Ethics statement: The study protocol was approved by Institutional Ethics Committee, Saveetha Dental College and Hospitals, Chennai, India (IHEC/SDC/MSIMPLANT-2303/24/038).

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