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CBCT-based evaluation of inferior turbinate morphometry and uncinate process anatomy in relation to maxillary sinus mucosal thickness

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Abstract

Objectives: To investigate the independent associations of inferior turbinate (IT) morphometrics and uncinate process (UP) anatomical variations with maxillary sinus mucosal thickness (MSMT) on cone-beam computed tomography (CBCT).

Methods: In this retrospective cross-sectional study, 200 sinus sides from 100 patients were evaluated. MSMT was measured and sides were classified as mucositis-positive (≥ 1 mm, $n = 100$) or mucositis-negative (< 1 mm, $n = 100$). IT dimensions (height, width, anteroposterior [AP] length, and volume) and UP characteristics (orientation, pneumatization, and superior attachment type) were assessed using On-Demand and ITK-SNAP software. Cluster-robust linear regression was performed to account for within-subject bilateral dependency and adjust for potential confounders.

Results: In the final adjusted multivariable model, IT height and IT AP dimension were the only variables independently associated with MSMT. Lower IT height was associated with greater MSMT ($P = 0.02$), whereas greater IT AP length was positively associated with MSMT ($P = 0.006$). In contrast, IT width ($P = 0.76$), IT volume ($P = 0.28$), UP orientation ($P = 0.51$), UP pneumatization ($P = 0.77$), and superior attachment type ($P = 0.45$) were not significantly associated with MSMT.

Conclusions: Dimension-specific IT parameters, particularly height and AP length, rather than overall IT volume or UP anatomical variation, were independently associated with maxillary sinus mucosal thickness. These findings suggest that localized turbinate geometry may be more relevant to mucosal thickening than generalized turbinate enlargement or uncinate process morphology.

Clinical Significance: Understanding the anatomical variations of the inferior turbinate and uncinate process on CBCT scans helps clinicians identify potential anatomical predisposing factors for maxillary sinus mucosal thickening, thereby improving diagnostic accuracy and treatment planning for sinonasal and rhinogenic pathologies prior to dental implant placement or sinus lift surgeries.

Keywords: Cone-beam computed tomography; Inferior turbinate; Maxillary sinus mucosa; Mucositis; Uncinate process.

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Introduction

Rhinosinusitis is a common inflammatory disorder of the sinonasal tract that substantially affects patients' quality of life, work productivity, and health care utilization. It is typically characterized by nasal obstruction, facial pressure, nasal discharge, and impaired olfaction, and may manifest as acute, recurrent, or chronic disease. Impaired ventilation and drainage of the paranasal sinuses are considered key contributors to the persistence and recurrence of mucosal inflammation within the maxillary sinus and other paranasal sinuses.[1–3] Because nasal obstruction is frequently related to underlying anatomical variations rather than purely functional or allergic causes, a detailed understanding of sinonasal anatomy and its variants is essential for both diagnosis and treatment planning [4,5]. The maxillary sinus drains through the principal maxillary ostium (PMO) into the ethmoidal infundibulum and then through the hiatus semilunaris and the middle meatus into the nasal cavity.[3,6,7] This drainage pathway, commonly referred to as the ostiomeatal complex (OMC) or ostiomeatal unit (OMU), is anatomically constrained by several adjacent structures, including the uncinate process, inferior turbinate, middle turbinate, ethmoid bulla, and surrounding ethmoidal cells.[6–8] Even subtle changes in the spatial relationship among these structures can influence sinus ventilation and mucociliary clearance and may predispose to mucus retention, mucosal thickening, and eventually rhinosinusitis.[2,7,9] Conversely, the presence of an anatomical variation does not necessarily imply functional obstruction, which underscores the need for careful radiologic–clinical correlation.[10]

The inferior nasal turbinate (inferior turbinate) is a key structure on the lateral nasal wall that plays a central role in regulating nasal airflow, humidification, and filtration.[8,11] Inferior turbinate hypertrophy may involve soft tissue, the bony component, or both, and can contribute to clinically significant nasal obstruction.[4,8,11] Chronic inflammatory conditions such as rhinitis and rhinosinusitis have been associated with hypertrophy of the inferior turbinate and with increased maxillary sinus mucosal thickness on the ipsilateral or even contralateral side.[6,21] Quantification of inferior turbinate morphology using linear dimensions (height, width, and anterior–posterior [AP] length) and volume allows a more objective assessment than subjective grading scales and may better reflect the anatomical burden that could impact sinonasal drainage [6,11,14]. The maxillary sinus is lined by pseudostratified ciliated columnar epithelium known as the Schneiderian membrane, which normally measures less than 1 mm in thickness.[1,3] Inflammatory processes, including rhinosinusitis and odontogenic sinusitis, may result in mucosal thickening, partial opacification, or complete opacification of the maxillary sinus.[1,2] Radiographically, maxillary sinus mucosal thickening of ≥ 1 mm is often considered indicative of mucositis, although the clinical significance of minimal thickening remains debated.[1,6,22] Several studies have explored the association between anatomical variations and maxillary sinus mucosal status, focusing on factors such as nasal septal deviation, concha bullosa, Haller cells, and inferior turbinate hypertrophy.[4,10,22–24] However, reported findings have not been entirely consistent, and many investigations have evaluated structures in isolation rather than as components of an integrated sinonasal drainage pathway.

The uncinate process of the ethmoid bone is another critical component of the OMC and a key surgical landmark in functional endoscopic sinus surgery (FESS).[7,13,18] Extending in a curved sagittal plane from the lateral nasal wall, it contributes to the formation of the ethmoidal infundibulum and helps define the relationship between the maxillary sinus ostium and the frontal recess.[7,12,13] The uncinate process

exhibits considerable morphological variability with respect to its angulation, course, superior attachment, and pneumatization.[13,15,19,23] Variants such as medially or laterally deviated uncinate processes, pneumatized uncinate processes, and different superior attachment types may narrow the ethmoidal infundibulum, alter the trajectory of mucus flow, and predispose to frontal, maxillary, or anterior ethmoidal sinus disease.[13,15,19,23] Because of this pivotal role, partial or complete uncinectomy is often performed during FESS to gain access to the ethmoidal infundibulum and the maxillary ostium and to restore sinus ventilation and drainage [18,20,23]. Cross-sectional imaging is indispensable for detecting sinonasal anatomical variations and evaluating their relationship with sinus pathology. Conventional computed tomography (CT) has long been considered the reference standard for imaging the paranasal sinuses and for preoperative mapping before FESS.[3,7,12,17] In recent years, cone-beam computed tomography (CBCT) has gained widespread acceptance in dentomaxillofacial radiology and increasingly in otorhinolaryngology, owing to its high spatial resolution, relatively low radiation dose, and high geometric accuracy for bony structures.[7,16] CBCT provides isotropic voxel data and multiplanar reconstructions that allow detailed assessment of the lateral nasal wall, OMC, and maxillary sinus, including evaluation of inferior turbinate morphometry, classification of uncinate process variants, and measurement of maxillary sinus mucosal thickness.[6,7,16,21] Furthermore, three-dimensional (3D) segmentation of the inferior turbinate and maxillary sinus can be performed to obtain volumetric measurements, enabling more comprehensive phenotyping than simple linear or categorical assessments.[11,21]

Several CBCT-based studies have assessed the effects of sinonasal anatomical variations on maxillary sinus morphology and mucosal findings. Some investigations have focused on the impact of nasal septal deviation, concha bullosa, and impacted teeth on maxillary sinus volume and dimensions, using approximate volume formulas or semi-automated measurements.[10,22,24] Others have examined the prevalence and distribution of uncinate process variants and their potential associations with chronic rhinosinusitis.[13,15,19,23] More recently, volumetric analyses of the inferior turbinate have been reported, including studies that explored the relationship between inferior turbinate volume and maxillary sinus mucosal thickness using 3D segmentation based on CT or CBCT data.[6,11,21] These studies suggest that increased inferior turbinate volume may be associated with greater maxillary sinus mucosal thickening, and that both ipsilateral and contralateral associations can be observed [6,21]. While individual anatomical variations of the ostiomeatal complex have been documented, few CBCT studies have evaluated these morphometric parameters simultaneously within a unified statistical model. Investigating these spatial and dimensional relationships collectively may provide a more comprehensive understanding of the anatomical factors associated with maxillary sinus mucosal changes.

Therefore, the present retrospective cross-sectional CBCT study was designed to investigate the relationship between inferior turbinate morphometry (particularly its volume and dimensional parameters) and the positional characteristics of the uncinate process of the ethmoid bone with the thickness of the maxillary sinus mucosa in adult patients. Specifically, we aimed (1) to quantify inferior turbinate volume and key morphometric dimensions (height, width, and anteroposterior length) using CBCT, (2) to characterize uncinate process position in terms of angulation, pneumatization, and superior attachment type, and (3) to evaluate the association of these parameters with maxillary sinus mucosal thickness. Our null hypothesis was that there is no significant association between inferior turbinate volume or uncinate process position and maxillary sinus mucosal thickness on CBCT images. Conversely, we hypothesized that specific inferior turbinate morphometric parameters, particularly height and anteroposterior length, would be independently associated with maxillary sinus mucosal

thickness, whereas uncinate process anatomical variants would exhibit either no independent association or only weak associations after adjustment for bilateral clustering and relevant covariates.

Materials and Methods

Ethical approval

This retrospective cross-sectional CBCT study was conducted in the Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Islamic Azad University, Tehran Medical Sciences, Tehran, Iran. The study protocol was approved by the institutional ethics committee (IR.IAU.PS.REC.1404.394) and was carried out in accordance with the Declaration of Helsinki and applicable national regulations. As only anonymized archived images were analyzed and no patient contact or intervention was involved, the requirement for informed consent was waived.

Study design and sample

This analytical retrospective cross-sectional study was based on archived CBCT scans obtained for routine diagnostic purposes involving the maxilla and sinonasal region during the academic year 2024–2025. Images were retrieved from the institutional digital archive and screened for eligibility. Sample size was estimated using the multiple regression power analysis module in PASS (NCSS, Kaysville, UT, USA). Based on a predefined significance level, statistical power, and expected effect size for the simultaneous evaluation of inferior turbinate volume and uncinate process position as predictors of maxillary sinus mucosal thickness, the minimum required sample size was calculated as 98 CBCT scans. To compensate for possible exclusions related to insufficient image quality or incomplete coverage of the region of interest, 100 scans were ultimately included. A purposive non-probability sampling strategy was adopted. Only one CBCT scan per patient was included. All scans had been acquired before the initiation of the study for routine diagnostic purposes unrelated to the present research question. The inclusion and exclusion criteria are summarized in Table 1.

Table 1. Study Population Characteristics and Selection Criteria

Criterion Type	Item	Description / Value
Demographics	Age (Years)	38.4±11.2
	Gender	Male: 46 (46.0%) / Female: 54 (54.0%)
Inclusion	Archived diagnostic CBCT	Scans including the maxilla and sinonasal region
	Adequate field of view	Visualization of MS, nasal cavity, IT, and UP
	Acceptable image quality	Minimal artefacts and adequate contrast
	Standardized head position	Neutral head position for reliable MPR
	Presence of maxillary teeth	Full maxillary dentition (excluding 3rd molars)
Exclusion	Previous sinonasal surgery	No history of sinonasal or maxillary surgery
	Craniofacial trauma	No midfacial or skull base trauma
	Sinonasal mass/polypsis	No masses or extensive nasal polyposis
	Marked unilateral IT hypertrophy	No pronounced unilateral enlargement
	Extensive posterior tooth loss	No multiple missing posterior teeth
	Odontogenic/maxillary lesions	No cysts, tumours, or large periapical lesions
	Sinus hypoplasia	No hypoplastic or incompletely developed MS
	Major craniofacial anomalies	No cleft-related or syndromic abnormalities

CBCT acquisition protocol

All CBCT examinations had been performed using the same CBCT unit (Genoray Papaya 3D Plus, Genoray Co., Ltd., Seoul, Korea). Scans were acquired with a large field of view (15 × 15 cm), a nominal isotropic voxel size of 0.3 mm, tube potential of 110 kVp, tube current of 4.3 mA, rotation time of 16 s, and an effective exposure time of approximately 9.5 s. All examinations were obtained by the same experienced radiographic technician according to a standardized positioning protocol. During image acquisition, patients were seated with the Frankfort horizontal plane parallel to the floor and the

midsagittal plane perpendicular to the floor. They were instructed to remain motionless, maintain light intercuspation, and avoid swallowing throughout scanning. [23, 7]

Image evaluation and measurements

CBCT datasets were exported in DICOM format and analyzed using OnDemand3D software (Cybermed Inc., Seoul, Korea) for multiplanar image review and linear measurements, and ITK-SNAP version 3.8.0 for three-dimensional segmentation and volumetric analysis. All image evaluations were performed on a calibrated diagnostic workstation in a dimly lit room. Datasets were reviewed in multiplanar reconstruction mode, and the axial, coronal, and sagittal planes were adjusted to obtain standardized sections through the maxillary sinuses and inferior turbinates. Slice thickness and spacing were kept constant across all cases [11, 19]. The operational definitions and measurement protocols for all study variables are presented in Table 2. Measurement of maxillary sinus mucosal thickness on axial, coronal, and sagittal images is illustrated in Figure 1.

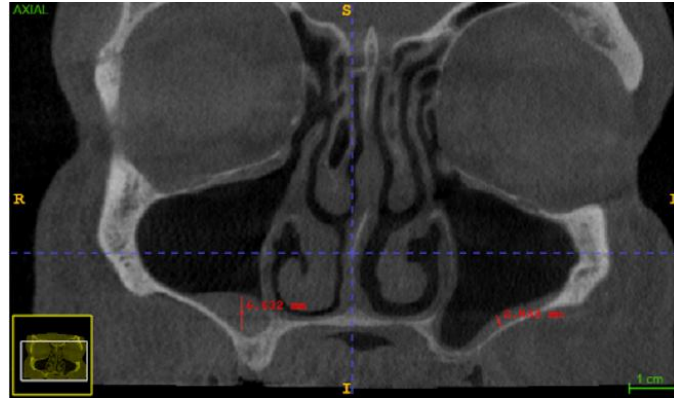


Figure 1: Coronal CBCT view illustrating the radiographic assessment of maxillary sinus mucositis. The mucosal thickness was measured at the most prominent point of the sinus floor using the software's linear measurement tool. Measurements ≥ 2 mm were categorized as mucositis-positive.

Linear measurements and segmentation of the inferior turbinate are shown in Figure 2.

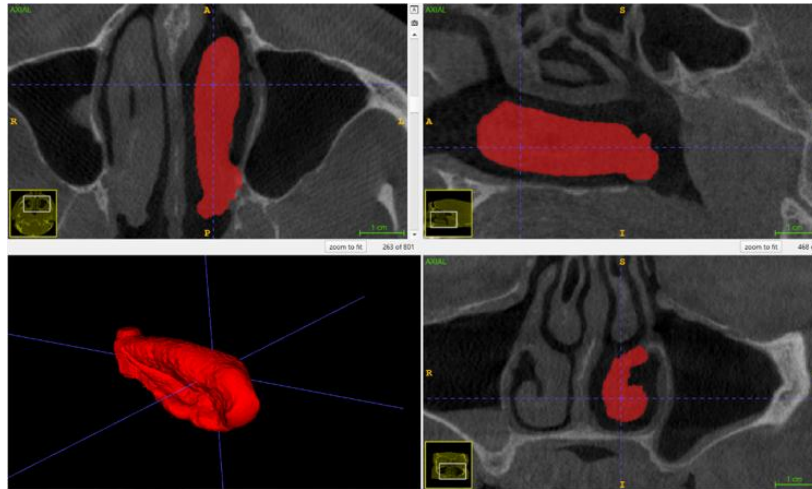


Figure 2. Methodology for inferior turbinate (IT) segmentation and volumetric analysis. The red overlay indicates the cross-sectional area of the IT in all three anatomical planes. The bottom-left panel displays the 3D rendered model of the IT, from which the total volume (mm^3) was derived for correlation with maxillary sinus mucositis.

Representative examples of uncinate process angular orientation and superior attachment type are presented in Figure 3, and uncinate process pneumatization is shown in Figure 4 [6, 19, 21].

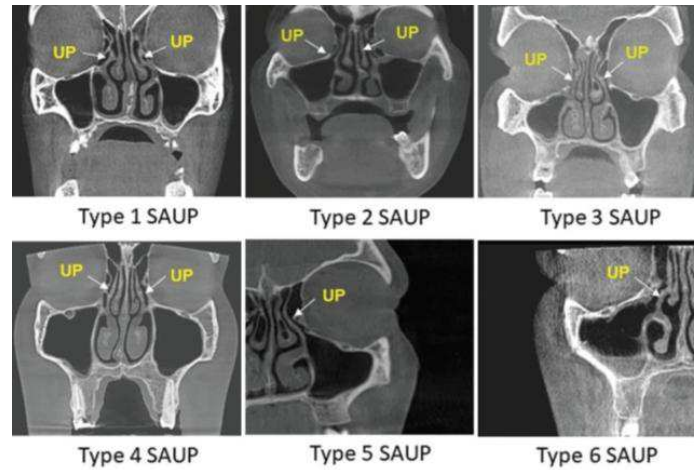


Figure 3. Representative coronal CT images illustrating the six patterns of superior attachment of the uncinate process (SAUP). The uncinate process is marked by yellow arrows and labeled “UP.” UP, uncinate process; SAUP, superior attachment of the uncinate process.



Figure 4. Representative coronal CBCT views of uncinate process (UP) pneumatization. The image illustrates the contrast between a solid (Left) and a pneumatized (Right) uncinate process. The presence of pneumatization was recorded as a binary variable in the anatomical assessment of the patients. UP: Uncinate Process.

Table 2. Operational Definitions and Measurement Units of Radiographic Parameters

Variable	Operational Definition and Measurement Method
IT Height (mm)	Measured on the coronal slice showing the maximum vertical dimension of the inferior turbinate (including both osseous core and overlying mucosa).
IT Width (mm)	Measured on the coronal slice showing the maximum horizontal dimension at the widest portion of the inferior turbinate.
IT AP Length (mm)	Measured on the sagittal slice as the maximum distance from the most anterior to the most posterior point of the inferior turbinate.
IT Volume (mm ³)	Calculated via semi-automatic three-dimensional segmentation using ITK-SNAP software.
UP Orientation	Categorized based on the angle of the uncinate process relative to the lateral nasal wall (Vertical, Oblique, or Horizontal).
UP Pneumatization	Defined as the presence or absence of air-filled cells (intrabony aeration) within the uncinate process.
SAUP Type	Classified according to the anatomical site of the superior attachment of the uncinate process (Types 1 to 6).
Mucosal Thickness (MT)	Measured as the maximum soft tissue thickness on the floor or walls of the maxillary sinus, classified as Normal (< 1 mm) or Thickened (≥ 1 mm).

Assessment of maxillary sinus mucosal thickness

Maxillary sinus mucosal thickness was assessed separately for the right and left sides using the Medical mode of OnDemand3D. Each sinus was evaluated in the axial, coronal, and sagittal planes. In accordance with previous studies, the Schneiderian membrane was examined at six predefined sites along the sinus floor: the mesial and distal aspects of the second premolar, first molar, and second molar regions. At each site, the maximum perpendicular thickness was measured in millimetres from the underlying bony wall to the inner mucosal surface. For each sinus, the highest value among the six measurements was recorded as the representative mucosal thickness [6, 7]. Consistent with previous literature, a mucosal thickness of ≥ 1.0 mm was considered indicative of mucositis. Accordingly, the sinuses were additionally categorized as mucositis or non-mucositis for descriptive and comparative purposes; however, in the primary statistical analyses, mucosal thickness was modeled as a continuous variable [1, 6].

Inferior turbinate morphometry and volume

Inferior turbinate morphometry was evaluated bilaterally using the Medical mode of OnDemand3D. Each turbinate was reviewed in the axial, coronal, and sagittal planes. Linear measurements were obtained as follows: height was defined as the maximum vertical distance in the coronal plane, width as the maximum mediolateral dimension in the coronal plane, and anteroposterior length as the distance between the most anterior and most posterior limits in the sagittal plane. The full extent of each inferior turbinate was first identified on axial images to ensure complete anatomical inclusion [4, 6, 11].

For volumetric analysis, semi-automatic three-dimensional segmentation was performed using ITK-SNAP software (version 3.8; www.itksnap.org). The anterior boundary was defined as the anterior-most point of the inferior turbinate bone, the posterior boundary as the posterior border of the turbinate body approaching the nasopharynx, the superior boundary as the attachment of the turbinate to the lateral nasal wall, and the inferior and medial boundaries as the free borders of the turbinate within the nasal cavity. Segmentation was performed using the Active Contour (Snake) algorithm with intensity thresholding to differentiate the turbinate from adjacent air spaces. Manual refinement was subsequently carried out slice-by-slice in the axial, coronal, and sagittal planes to correct for thin bony projections and imaging artifacts. Inferior turbinate volume was then calculated in cubic millimetres from the final segmented voxel set [6, 11].

Uncinate process position and variants

The uncinate process was evaluated bilaterally on CBCT images in the axial, coronal, and sagittal planes. Two principal features were assessed: angular orientation in the sagittal plane and superior attachment pattern in the coronal plane according to the Landsberg and Friedman classification. Sagittal angular orientation relative to the vertical plane of the lateral nasal wall was categorized as normal (10° – 30°), mesial/horizontal ($>30^{\circ}$), or lateral/vertical ($<10^{\circ}$). In the coronal plane, the superior attachment of the uncinate process (SAUP) was classified into six types: type 1, lamina papyracea; type 2, posterior wall of the agger nasi cell; type 3, lamina papyracea and the junction of the middle turbinate with the cribriform plate; type 4, junction of the middle turbinate with the cribriform plate; type 5, ethmoidal roof (skull base); and type 6, middle turbinate. The presence or absence of uncinate process pneumatization (uncinate bulla) was also recorded (Figures 3 and 4) [13, 19, 23].

Observer Reliability and Validation

All CBCT images were independently evaluated by two experienced dentomaxillofacial radiologists who were blinded to the patients' clinical data. To assess measurement reliability, both intra-observer and inter-observer agreement analyses were performed on a randomly selected subset comprising 20% of the sample ($n = 40$ sides). For intra-observer reliability, the primary investigator repeated all measurements after a four-week interval to minimize recall bias. For inter-observer reliability, the second radiologist independently assessed the same subset. Continuous variables, including inferior

turbinate volume, height, width, anteroposterior dimension, and maxillary sinus mucosal thickness, were evaluated using the intraclass correlation coefficient (ICC; two-way mixed-effects model, absolute agreement). Categorical and ordinal variables, including uncinate process angular orientation, SAUP type, and uncinate pneumatization, were assessed using Cohen's kappa for intra-observer agreement and Fleiss' kappa for inter-observer agreement. ICC and kappa values >0.80 were considered indicative of excellent agreement [11, 19].

Outcome variables

The primary outcome variable was maxillary sinus mucosal thickness (mm), measured separately for each side and analyzed as a continuous variable. This approach was adopted to preserve measurement granularity and reduce the loss of information associated with dichotomization. Secondary outcomes included the categorical presence of mucositis, defined as mucosal thickening ≥ 1.0 mm, as well as the assessment of ipsilateral and contralateral associations between sinonasal anatomical variables and mucosal thickness. The principal predictor variables were inferior turbinate volume (mm^3), inferior turbinate linear dimensions (height, width, and anteroposterior length), uncinate process angular orientation, superior attachment type of the uncinate process (Landsberg types 1–6), and uncinate process pneumatization status. Age, sex, and side were treated as potential confounders in the analytical models. Cases with obvious anatomical or pathological confounders were excluded a priori, as detailed in Table 1 [6, 19, 21, 24].

Statistical analysis

All statistical analyses were performed using SPSS software (version 26.0; IBM Corp., Armonk, NY, USA). Descriptive statistics were computed, presenting means and standard deviations (SD) for normally distributed continuous variables, medians and interquartile ranges (IQR) for non-normally distributed variables, and frequencies and percentages for categorical variables. The normality of continuous distributions was evaluated using the Shapiro–Wilk test in conjunction with visual inspections of histograms and Q–Q plots. To account for the nested structure of the dataset specifically, the within-subject correlation resulting from bilateral measurements (left and right maxillary sinuses) obtained from 100 individual patients ($N = 200$ observations) generalized estimating equations (GEE) with a linear link function and an exchangeable working correlation matrix were employed for both univariable and multivariable analyses. Robust Huber–White sandwich estimators were utilized to calculate cluster-adjusted standard errors (SE) and 95% confidence intervals (95% CI), thereby preventing the artificial inflation of Type I error rates due to intra-subject dependency [10, 21]. Variable selection for the multivariable GEE model was guided by clinical relevance and preliminary univariable screenings; variables exhibiting a P -value < 0.20 in univariable analyses, or established clinical confounders (such as age and sex), were candidates for the final model.

Multicollinearity among predictors was assessed using the Variance Inflation Factor (VIF), with a tolerance threshold of $\text{VIF} < 5$. Standardized beta coefficients (β_{std}) were calculated to compare the relative effect sizes of the continuous predictors. To control for multiple testing across the multiple inferior turbinate and uncinate process parameters, P -values from the multivariable model were adjusted using the Benjamini–Hochberg False Discovery Rate (FDR) procedure. A two-sided adjusted P -value < 0.05 was considered statistically significant [6, 21, 22]. Intraobserver and interobserver reliability were assessed on a randomly selected subset comprising 20% of the CBCT scans (representing 40 sides), re-evaluated after a two-week interval. For continuous measurements (including inferior turbinate volume, linear dimensions, and mucosal thickness), the intraclass correlation coefficient (ICC; two-way mixed-effects model, absolute agreement) was computed. For categorical and ordinal variables (uncinate process orientation, SAUP type, and uncinate pneumatization), agreement was quantified using Cohen's

kappa statistic. Reliability coefficients were interpreted according to standardized clinical benchmarks [11, 19].

Results

Reliability of Measurements

To establish the reproducibility of the radiographic measurements, a random subset of 20 CBCT scans (representing 40 sides) was re-evaluated after 2 weeks. Intra- and interobserver reliability analyses demonstrated excellent agreement. For continuous variables (inferior turbinate dimensions and volume), the intraobserver intraclass correlation coefficient (ICC) ranged from 0.96 to 0.99 (95% CI: 0.93–0.99), and the interobserver ICC ranged from 0.93 to 0.98 (95% CI: 0.89–0.98). For categorical variables (uncinate process orientation, pneumatization, and SAUP type), the intraobserver Cohen's kappa values ranged from 0.84 to 0.95, while the interobserver kappa values ranged from 0.80 to 0.92, indicating substantial to almost perfect agreement.

Study Population and General Characteristics

A total of 100 patients were included in the study, contributing 200 side-level observations. The study sample was equally distributed according to maxillary sinus mucositis status, with 100 mucositis-positive sides and 100 mucositis-negative sides. Descriptive, bivariate, and multivariable analyses were subsequently performed to evaluate the association between sinonasal anatomical variations and maxillary sinus mucosal thickness.

Inferior Turbinate Dimensions and Volume

The comparative analysis of inferior turbinate (IT) morphometric parameters according to CBCT-defined mucosal thickening (≥ 1 mm) status is detailed in Table 3. The mean IT height was slightly lower on sides with mucosal thickening than on sides with normal mucosal thickness (16.49 ± 2.69 mm vs. 17.17 ± 2.57 mm), although this difference did not reach statistical significance ($P = 0.069$). Conversely, IT width (10.21 ± 2.46 mm vs. 9.54 ± 2.18 mm; $P = 0.043$), anteroposterior (AP) dimension (47.40 ± 6.29 mm vs. 43.01 ± 6.40 mm; $P < 0.001$), and total volume (6201.51 ± 2099.92 mm³ vs. 5248.41 ± 1958.86 mm³; $P = 0.010$) were significantly greater on sides presenting with mucosal thickening. The largest bivariate difference was observed for the IT AP dimension.

Table 3. Inferior turbinate morphometric parameters stratified by maxillary sinus mucositis status

Parameter	Normal Mucosa (<1 mm) (n=100)	Mucosal Thickening (≥ 1 mm) (n=100)	P-value
Height (mm)	17.17 ± 2.57	16.49 ± 2.69	0.069
Width (mm)	9.54 ± 2.18	10.21 ± 2.46	0.043
AP dimension (mm)	43.01 ± 6.40	47.40 ± 6.29	<0.001
Volume (mm ³)	5248.41 ± 1958.86	6201.51 ± 2099.92	0.010

Note: Values are expressed as mean $\pm$ standard deviation (SD). P-values were derived from generalized estimating equation (GEE) models with robust sandwich standard errors to account for within-subject correlation (bilateral measurements per patient).

Uncinate Process Orientation

The distribution of uncinate process (UP) orientation categories by mucositis status is illustrated in Figure 5. The ‘normal’ orientation (10° – 30°) predominated in both cohorts, accounting for 96.0% of the mucositis-negative group and 90.0% of the mucositis-positive group. Mesial/horizontal orientation ($> 30^\circ$) was observed in 9.0% of mucositis-positive sides compared to 2.0% of mucositis-negative sides, while vertical/lateral orientation ($< 10^\circ$) was rare in both groups (1.0% vs. 2.0%, respectively). Bivariate analysis demonstrated that the overall distribution of UP orientation categories did not differ significantly between the two groups (Chi-square test, $P = 0.083$).

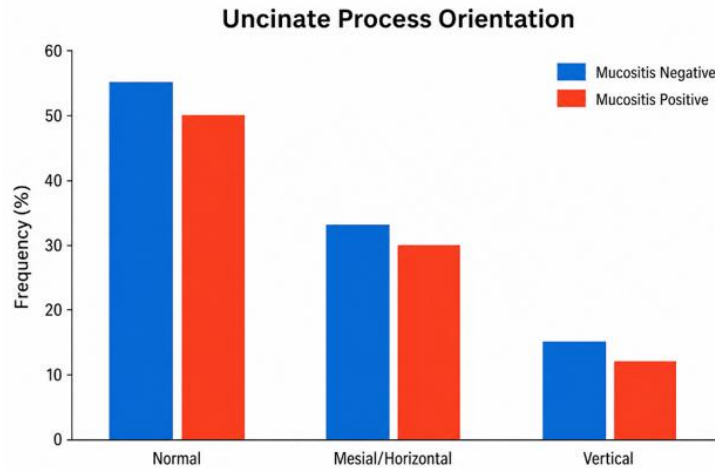


Figure 5. Distribution of uncinate process (UP) orientation categories stratified by the presence of maxillary sinus mucositis. The ‘normal’ orientation was the most prevalent phenotype in both study cohorts. There was no statistically significant association between UP orientation categories and the presence of mucositis (chi-square test; $P = 0.083$).

Uncinate Process Pneumatization

The relationship between UP pneumatization and mucositis is summarized in Table 4. Pneumatization of the UP was detected at identical frequencies in both the mucositis-negative and mucositis-positive groups (62.0% in each cohort). Bivariate logistic regression confirmed the complete absence of an association between UP pneumatization and mucositis status (Odds Ratio [OR] = 1.00, 95%Confidence Interval [CI]: 0.71–1.41, $P = 1.000$).

Table 4. Association between uncinate process pneumatization and maxillary sinus mucositis status

UP Pneumatization	Mucosal Thickening Negative ($n = 100$)	Mucosal Thickening Positive ($n = 100$)	Odds Ratio (OR)	95% Confidence Interval (CI)	P -value
Absent	38 (38.0%)	38 (38.0%)	1.00	Reference	-
Present	62 (62.0%)	62 (62.0%)	1.00	0.71–1.41	1.000

Note: n represents the number of sinus sides. Odds ratios and P -values were derived from univariable generalized estimating equation (GEE) logistic models with robust sandwich standard errors to account for within-subject clustering (bilateral measurements per patient).

Data are presented as count (percentage). Odds ratios were calculated using the absence of uncinate process pneumatization as the reference category.

Superior Attachment of the Uncinate Process (SAUP)

The distribution of the superior attachment of the uncinate process (SAUP) categories according to Landsberg–Friedman classification is displayed in Figure 6 and detailed in Table 5. Overall, Type 2 and Type 4 attachments were the most prevalent patterns. Type 2 attachments were more frequent in mucositis-negative sides (34.0% vs. 26.0%), whereas Type 4 attachments were more common in mucositis-positive sides (44.0% vs. 28.0%). Type 5 was the least frequent variation overall and was entirely absent in the mucositis-positive cohort (0.0% vs. 8.0%). An omnibus Chi-square test revealed a statistically significant difference in the overall distribution of SAUP categories between the two groups ($P = 0.045$). However, category-specific odds ratios for sparse cells (specifically Type 5) were mathematically unstable, as reflected by the inestimable confidence interval.

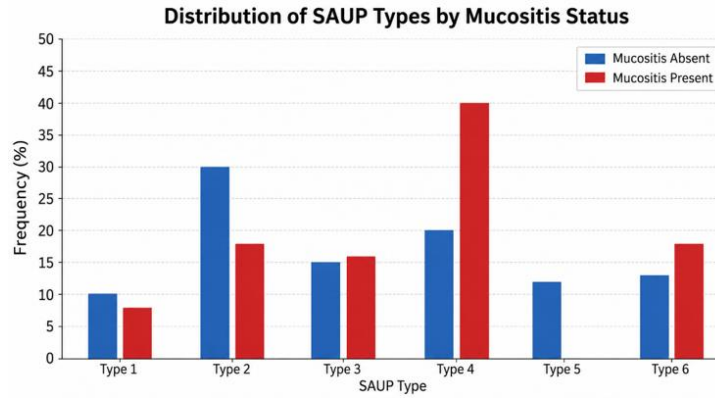


Figure 6. Distribution of superior attachment of the uncinate process (SAUP) categories (Landsberg–Friedman classification) stratified by maxillary sinus mucositis status. Types 2 and 4 were the most prevalent attachments observed in both cohorts. A significant association was noted between SAUP types and mucositis status (chi-square test; $P = 0.045$), with Type 2 being more frequent in the non-mucositis group and Type 4 in the mucositis group.

Table 5 Association between superior attachment of the uncinate process (SAUP) type and mucositis status

SAUP Type	Mucositis Positive (n=100)	Mucositis Negative (n=100)	Odds Ratio	95% CI	P-value
Type 1	12 (12.0%)	14 (14.0%)	Reference	—	—
Type 2	26 (26.0%)	34 (34.0%)	0.89	0.39–2.02	0.770
Type 3	18 (18.0%)	16 (16.0%)	1.31	0.51–3.34	0.540
Type 4	44 (44.0%)	28 (28.0%)	1.83	0.79–4.24	0.150
Type 5	0 (0.0%)	8 (8.0%)	NE	NE	—

Note: Abbreviations: CI, confidence interval; NE, not estimable due to data separation (zero cells in the mucositis-positive group). Category-specific odds ratios for SAUP Type 5 were not estimable due to data separation (zero-cell in the mucositis-positive cohort)

Multivariable Regression Analysis

To assess the independent contribution of anatomical variations to mucosal thickness while adjusting for confounding and accounting for patient-level clustering, a multivariable linear regression model was constructed (Table 6). After adjusting for all covariates, only IT height ($\beta = -0.23$, 95%CI: -0.37 to -0.09 , $P = 0.007$) and IT AP dimension ($\beta = 0.07$, 95%CI: 0.00 to 0.14 , $P = 0.046$) remained statistically significant independent predictors of maxillary sinus mucosal thickness. Other parameters, including IT width, IT volume, UP orientation, UP pneumatization, and SAUP type, showed no significant independent association with mucosal thickness in the fully adjusted model.

Table 6. Multivariable linear regression model predicting maxillary sinus mucosal thickness ($N = 200$ observations from 100 patients)

P-value	95% CI	SE	β Coefficient	Reference category / scale	Predictor
0.490	[−, 3.918.19]	3.09	2.14	—	Intercept
0.007	[−, 0.37 – 0.09]	0.07	−0.23	Continuous	IT height (mm)
0.760	[−, 0.170.23]	0.10	0.03	Continuous	IT width (mm)
0.046	[0.00, 0.14]	0.04	0.07	Continuous	IT AP dimension (mm)
0.280	[−, 0.040.14]	0.05	0.05	Continuous (scaled)	IT volume (per 1000 mm ³)
0.510	[−, 1.192.41]	0.92	0.61	Normal orientation	UP orientation: Mesial
0.800	[−, 2.461.90]	1.11	−0.28	Normal orientation	UP orientation: Vertical
0.770	[−, 0.560.74]	0.33	0.09	Absent	UP pneumatization: Present
0.770	[−, 1.381.02]	0.61	−0.18	Type 1	SAUP Type 2
0.720	[−, 1.051.53]	0.66	0.24	Type 1	SAUP Type 3
0.560	[−, 0.941.72]	0.68	0.39	Type 1	SAUP Type 4
0.590	[−, 2.191.25]	0.88	−0.47	Type 1	SAUP Type 5

Note: β coefficients represent the estimated change in maxillary sinus mucosal thickness (in millimeters) associated with a one-unit increase in the continuous predictors, or relative to the specified reference category for categorical predictors, holding all other covariates constant. Bold P-values indicate statistically significant associations ($P < 0.05$). Standard errors (SE) and 95% confidence intervals (95% CI) are adjusted for patient-level clustering (within-subject correlation between left and right maxillary sinuses) using robust sandwich estimators. AP, anteroposterior; IT, inferior turbinate; SAUP, superior attachment of the uncinate process; UP, uncinate process.

Abbreviations: AP: anteroposterior; UP: uncinate process; SAUP: superior attachment of the uncinate process; SE: standard error; CI: confidence interval. Dependent variable: Maxillary sinus mucosal thickness (mm). Bold P-values indicate statistical significance ($P < 0.05$). Standard errors and confidence intervals are adjusted for patient-level clustering.

Discussion

The present study evaluated anatomical correlates of maxillary sinus mucosal thickness using side-level morphometric assessment and regression modeling that accounted for within-subject clustering. The main finding was that specific inferior turbinate (IT) dimensions, rather than volumetric enlargement alone, were independently associated with greater mucosal thickness. In the adjusted analysis, increased anteroposterior (AP) length and reduced IT height showed the most consistent associations. These findings extend prior CBCT-based observations linking IT morphology to sinonasal mucosal change and suggest that turbinate geometry may be more informative than overall size alone when assessing structural relationships with maxillary sinus mucosal thickening [6,21]. A plausible interpretation is that AP and vertical variations in IT morphology may influence local airflow distribution within the nasal cavity and adjacent ostiomeatal region. From this perspective, AP elongation may increase the extent of aerodynamic interaction along the lateral nasal wall, whereas reduced vertical height may be associated with less favorable airflow organization, impaired local ventilation, or reduced efficiency of mucociliary clearance. Such mechanisms could contribute to an environment in which mucosal thickening is more likely to develop or persist. However, given the cross-sectional nature of the present study, these interpretations remain mechanistic hypotheses rather than causal explanations.

By contrast, uncinate process (UP) orientation, superior attachment pattern, and pneumatization were not independently associated with mucosal thickness after adjustment for the other anatomical variables. This observation differs somewhat from earlier studies emphasizing the anatomical and surgical relevance of UP variation [19,23]. That said, the absence of statistical significance in the present analysis should not be interpreted as conclusive evidence of no effect. Rather, it may reflect limited power for less frequent variants, context-dependent effects, or the possibility that any contribution of UP-related anatomy is smaller than that of IT geometry in the present dataset. The inverse association between IT height and mucosal thickness is particularly noteworthy because it challenges the simplified assumption that larger turbinate size is uniformly disadvantageous. Previous discussions have often framed turbinate-related sinonasal disease in terms of generalized hypertrophy or increased overall volume [6]. In contrast, the present findings suggest that a more specific geometric pattern, characterized by reduced height and increased AP dimension, may be more relevant to mucosal thickening than enlargement per se. This distinction may help explain why gross turbinate size alone does not consistently correspond to sinus mucosal status across patients. Further studies incorporating computational airflow analysis or physiologic assessment would be valuable for testing this interpretation more directly.

A methodological strength of this study lies in the integration of bilateral side-level measurements with multivariable analysis that explicitly accounted for clustering within individuals. Evaluating 200 sinus sides from 100 patients allowed side-specific anatomical variation to be examined without treating paired observations as statistically independent. In addition, the combined assessment of IT dimensions, IT volume, UP orientation, superior attachment type, and UP pneumatization provided a broader anatomical framework than approaches focused on a single feature. These design elements improve the internal interpretability of the observed associations, although they do not overcome the inherent constraints of observational cross-sectional data. Several limitations should be acknowledged. First, the retrospective cross-sectional design precludes causal inference. Second, single-center purposive sampling may limit generalizability. Third, residual confounding from unmeasured clinical factors most notably allergic status and sinonasal symptom burden cannot be excluded. Finally, the relatively infrequent distribution of certain uncinate process variations (e.g., Type 5 SAUP) reduced statistical power for detecting subtle associations. Future prospective studies with comprehensive clinical phenotyping are warranted to clarify these anatomical contributions to sinus health.

Conclusion

The present CBCT-based study highlights the independent role of specific inferior turbinate (IT) dimensions in relation to maxillary sinus mucosal thickening. Our multivariable analysis, adjusted for patient-level clustering and anatomical confounders, demonstrated that decreased IT height and increased anteroposterior (AP) dimension are significantly associated with greater mucosal thickness. Notably, despite their traditional emphasis in anatomical literature, global IT volume, uncinate process orientation, and pneumatization did not emerge as independent predictors of mucosal status in the final adjusted model. While a global association was observed for superior attachment of the uncinate process (SAUP) in bivariate comparisons, its clinical significance as a standalone predictor remains secondary to turbinate morphometry. These findings suggest that a granular, dimension-specific assessment of the inferior turbinate may offer superior diagnostic value compared to global volumetric or uncinate process evaluations in identifying patients at risk for sinus mucosal changes. Due to the retrospective nature of this study, these associations should be interpreted as exploratory, necessitating longitudinal investigations to clarify the pathophysiological mechanisms underlying these anatomical markers.

Conflicts of interest

The authors declare no conflict of interest.

Funding

Not applicable.

Ethics approval

This retrospective cross-sectional CBCT study was conducted in the Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Islamic Azad University, Tehran Medical Sciences, Tehran, Iran. The study protocol was approved by the institutional ethics committee (IR.IAU.PS.REC.1404.394) and was carried out in accordance with the Declaration of Helsinki and applicable national regulations. As only anonymized archived images were analyzed and no patient contact or intervention was involved, the requirement for informed consent was waived.

Informed consent

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5). Informed consent was obtained from all patients for being included in the study.

Declarations**Ethics approval**

This study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Ethics Committee of Islamic Azad University of Medical Sciences, Tehran, Iran (ethics approval code: **IR.IAU.PS.REC.1404.394**).

Consent to participate

Written informed consent was obtained from all participants before CBCT imaging. The use of the acquired CBCT images for research purposes was conducted in accordance with the approval of the institutional Ethics Committee.

Consent to publish

Not applicable. This study does not contain any individual person's identifiable data or images.

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Data availability

The datasets generated and/or analyzed during the current study are not publicly available because they comprise patient-derived CBCT data and are subject to institutional and ethical restrictions. Data may be available from the corresponding author upon reasonable request, subject to approval by the relevant ethics committee and institutional authorities.

Author contributions

F.M. conceived and designed the study. **F.M.** and **H.K.** contributed to data collection and CBCT assessment. **L.H.** and **H.K.** contributed to data analysis and interpretation. **F.M.** drafted the manuscript. All authors critically revised the manuscript, approved the final version, and agreed to be accountable for all aspects of the work.

Competing interests

The authors declare that they have no competing interests.

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