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A Radiological Evaluation of the Nasomaxillary Complex in Relation to Non-Odontogenic Maxillary Sinusitis: A Retrospective CBCT Study

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Abstract:

Background: Anatomical variations in the nasomaxillary complex are prevalent and may influence the morphology of the paranasal sinuses. Cone-beam computed tomography (CBCT) provides an accurate three-dimensional assessment of these variations and their relationship to surrounding sinonasal structures. Characterizing such anatomical patterns may aid in understanding maxillary sinus changes and provide useful information for dental and maxillofacial treatment planning.

Methods: For this study, 350 CBCT scans from Egyptian patients were retrospectively selected. Coronal CBCT scans of the bilateral paranasal sinuses were evaluated to assess middle turbinate variations and the degree of nasal septal deviation. Additionally, the relationship between the superior attachment of the uncinate process and the variations of the nasomaxillary complex attachment was investigated. Statistical analysis was performed using the chi-square test and one-way ANOVA.

Results: Among the 350 right and 350 left sides examined, concha bullosa was identified in 137 scans (19.6%), while lamellar concha bullosa was noted in 144 scans (20.6%). Pneumatization of the middle turbinate was identified in 210 images (60%) while paradoxical configuration of the middle turbinate was seen in both sides at 44 images (12.5%). The average deviation of the nasal septum was 9.50 ± 3.52 °, A highly statistically significant association was observed between the superior attachment of the uncinate process and maxillary sinus mucosal thickening on both the right ($p=0.02$ and left side ($p < 0.001$).

Conclusion: The superior attachment of the uncinate process demonstrated the strongest association with maxillary sinus mucosal thickening among the anatomical variations evaluated using CBCT. Increased mucosal thickening was also associated with other sinonasal morphological variations, including nasal septal deviation, paradoxical middle turbinate, and middle turbinate pneumatization, although to varying degrees.
Keywords: Cone-Beam CT; Paranasal Sinuses; Osteomeatal Complex; Ethmoid Bone

I. Background:

The maxillary sinuses are the largest of the paranasal sinuses and represent the earliest structures to develop within the maxillary region, situated between the nasal and orbital cavities. Inflammation of the mucosal lining of the maxillary sinus, known as the sinus membrane, is termed sinusitis. Alterations affecting the nasal cavities constitute the principal etiology of this condition, which is consequently classified as non-odontogenic sinusitis (1,2). Maxillary sinusitis is a common inflammatory disorder with a multifactorial origin and is associated with substantial morbidity. In cases of rhinogenic rather than odontogenic origin, the disease process begins with nasal inflammation, progresses to involvement of the anterior ethmoid region, and is followed by secondary obstruction of the ostiomeatal unit(3). A bidirectional relationship exists between the upper and lower respiratory tracts, whereby pathological conditions and therapeutic interventions affecting one region may influence the other. The association between chronic rhinosinusitis and asthma represents a well-recognized example of this interrelationship.(3)

The anatomical area on the lateral nasal wall **(**known as the osteomeatal complex (OMC **)**contains the drainage routes connecting the anterior ethmoid, maxillary, and frontal sinuses to the nasal cavity for drainage and ventilation(4,5). The maxillary sinus ostium, ethmoidal infundibulum, uncinate process, ethmoidal bulla, semilunar hiatus, frontal recess, middle meatus, and middle conchae are all part of the OMC(6). A concha bullosa indicates the existence of an air cell within the turbinate, whereas the middle turbinate (MT) concha bullosa is a frequently seen anatomical abnormality in the nasal cavity (7,8). The margin of a paradoxical middle turbinate has a medial curvature, with the concave side facing the nasal septum (9). The nasal septum (NS) facilitates easy airflow and acts as the nostrils' medial border. It is susceptible to deviations caused by the developmental process (10). The maxillary and frontal sinus ostium are covered medially by uncinate process (UP), a thin sickle-shaped projection that resembles a hook on the lateral wall of the nose(11,12).

The OMC serves as the fundamental functional unit governing the mucociliary clearance and ventilation of the anterior ethmoidal, frontal, and maxillary sinuses(13,14). Anatomical variations or mechanical obstructions within the OMC such as uncinate process deviations or concha bullosa can significantly impair the patency of the sinus outflow tract(15). This disruption of physiological drainage often triggers a cascade of chronic inflammatory responses, culminating in localized or generalized maxillary sinus mucosal thickening(16).

Conventional radiographs are commonly employed in the diagnosis of odontogenic maxillary sinusitis; however, their diagnostic value may be restricted by the superimposition of osseous structures within the region of interest The routine use of multi-detector CT is limited by its high radiation dose and significant costs. Additionally, this technology is often difficult to access within the scope of rhinology and maxillofacial diagnostics(3,17,18). Cone-beam computed tomography (CBCT) has been extensively utilized as an adjunctive imaging modality for the assessment of the paranasal sinuses. In CBCT examinations, the maxillary sinus typically presents as a completely hypodense cavity delineated by well-defined bony boundaries. The presence of sinus clouding, manifested as opacification, is indicative of mucosal thickening that may result in near-complete

occlusion of the sinus cavity(2). To support the appropriate use of CBCT in dental practice, the European Academy of Dentomaxillofacial Radiology (EADMFR) developed training guidelines for dentists involved in CBCT imaging. According to these guidelines, Level 1 competency encompasses CBCT operation and the recognition of normal and pathological dentomaxillofacial structures, whereas Level 2 competency emphasizes the differentiation of normal anatomical findings from disease-related alterations affecting the teeth, jaws, and facial skeleton(19).

Nevertheless, there is still a significant absence of research that precisely assesses the morphological correlation between various nasomaxillary variations and the severity of non-odontogenic maxillary sinusitis, despite the diagnostic benefits of CBCT (20) .The current study was conducted to close this knowledge gap and clarify the relationship between the osteomeatal complex and maxillary sinus pathology, given the crucial implications of these anatomical relationships for both surgical planning and clinical management in otorhinolaryngology. The main goals were to measure nasal septal deviation by analyzing the coronal cut of the full-volume craniofacial and to determine the frequency of middle turbinate morphological variations. Additionally, the study aimed to clarify how the anatomical differences within the nasomaxillary complex relate with each another, particularly in regard to non-odontogenic maxillary sinusitis.

II. Methods:

II.a. Study population:

This study aimed to assess, using cone-beam computed tomography, the relation between anatomical variations of nasomaxillary complex morphology in cases of non-odontogenic maxillary sinusitis.

This retrospective cross-sectional observational study evaluated CBCT scans obtained from the digital archives involving a study population of 350 Egyptian subjects (147 men, 203 women). The dataset was curated from the digital archives of the Department of Oral and Maxillofacial Radiology at Ain Shams University, spanning a temporal range from 2023 to 2025. In accordance with the previously established power analysis, this sample size was selected to ensure sufficient statistical rigor for the intended anatomical evaluations.

Candidate scans were selected based on the availability of full-volume craniofacial CBCT records of optimal diagnostic quality. To maintain the anatomical integrity of the sample and prevent confounding factors, the study excluded cases involving patients under 12 years of age to ensure the analysis focused on mature anatomy (21),a history of sinonasal surgical interventions, maxillofacial trauma, syndromes, congenital anomalies or neoplastic processes within the nasomaxillary complex. Furthermore, any sinus pathologies determined to be of odontogenic origin were strictly excluded from the analysis such as apical periodontitis, dental trauma, tooth extraction, and implant placement, periodontitis.

II.b. Image acquisition:

The radiographic material consisted of full-volume craniofacial CBCT datasets, with a primary focus on the assessment of coronal reconstructions. All imaging records were acquired using the I-CAT™ Next Generation system (Imaging Sciences International, Hatfield, Pennsylvania, USA), ensuring standardized acquisition parameters and high-resolution diagnostic quality for the visualization of the nasomaxillary and paranasal structures, utilized a tube voltage of 120 kVp and a tube current of 5 mA, with exposure parameters tailored to the specific voxel dimensions and field of view selected.

II.c. Image visualization:

The CBCT acquisition protocol Subsequent image visualization and volumetric analysis were conducted via the OnDemand3D Communicator software, Version 1.0.11.1007.081122

(Cybermed Inc., Seoul, South Korea). To facilitate optimal image evaluation, all scans were meticulously examined after adjustment of brightness, contrast, and magnification parameters displayed on a 32-inch high-definition monitor with a resolution of 1366 x 768 pixels.
To determine the reproducibility of the radiographic evaluations, reliability analyses between and among observers were carried out. Two oral radiologists who were blind to clinical information and each other's conclusions independently evaluated. In order to reduce memory bias, the principal investigator reassessed the same image selection for intra-observer reliability four weeks later.

II.d. Standardized CBCT Protocol for Assessing Nasomaxillary Anatomical Variations and Their Relationship with Maxillary Sinus Mucosal Thickening:

For standardized radiographic evaluation of the bilateral paranasal sinuses, coronal CBCT reconstructions were oriented to assess nasomaxillary anatomical variations specifically the UP, MT, and nasal septum deviation (NSD) and their relationship with non-odontogenic maxillary sinus mucosal thickening. Methodological consistency was achieved by aligning the coronal plane until the bilateral maxillary sinus ostia were concurrently visualized in a single reconstruction. This specific anatomical landmark served as a reference point to establish a uniform analysis plane across the study cohort, ensuring reliable morphological characterization and comparative measurements. Evaluations were performed by 2 oral and maxillofacial radiologists.

Qualitative measurements:

1- Pneumatization of the MT was evaluated on coronal cut and categorized into: (8) **(**figure 1**)**

- lamellar (including the vertical lamella of the middle turbinate) (figure 1A)**.**
- concha bullosa (including the lower part of the middle turbinate) (figure 1B).
- Unilateral or bilateral pneumatization or paradoxical middle turbinate (figure 1C) was identified as a type of variation.

Quantitative measurements:

2- Measurement the NSD on coronal cut; the angle between the crista galli and the most noticeable point of deviation was used to calculate the angle of deviation. The direction of deviation was determined by the convex portion of the nasal septum. Patients were then categorized into three groups based on NSD severity (22) (figure 2):

- mild (less than 9°) (figure 2A).
- moderate (9°-15°) (figure 2B).
- severe (greater than 15°) (figure 2C).

3-The presence of sinus mucosal thickening was measured at the point of maximum thickness from the sinus floor using the reference line. The horizontal line was positioned at the deepest point in the maxillary sinus floor, and the vertical line was used to measure the mucosal thickening at the right and left of the maxillary sinus. The radiographic signs of maxillary sinusitis were evaluated using the same adjusted coronal cut. The radiographic findings were subsequently recorded and categorized into three groups (23) **(**figure 3):

- Grade 1 (normal mucosal thickening, 0 to 2 mm) (figure 3A).
- Grade 2 (moderate mucosal thickening, 2 to 10 mm) (figure 3B)
- Grade 3 (severe mucosal thickening) (figure 3C).

4- Evaluation of the superior attachment and anatomical variations of the uncinate process in relation to maxillary sinus mucosal thickening**:**

Based on the morphological pattern of the superior attachment proposed by Landsberg and Friedman(24) as follows: Type 1: Superior attachment to the lamina papyracea; Type 2: Superior attachment to the wall of the agger nasi cell; Type 3: Superior attachment extending to both the

lamina papyracea and the junction of the middle turbinate with the cribriform plate; Type 4: Superior attachment to the junction of the middle turbinate and the cribriform plate; Type 5: Superior attachment to the ethmoid skull base; and Type 6: Superior attachment to the middle turbinate.

In cases where no distinct superior attachment could be identified, the uncinate process was recorded as having a blunt configuration, and its angulation was measured as the angle formed between the uncinate process and a horizontal line drawn from its superior edge(4,25).

The presence or absence of uncinate process pneumatization (uncinate bulla) was also recorded. In addition, cases in which the uncinate process lacked a definable superior attachment due to were documented.

These anatomical variations of the uncinate process were subsequently evaluated in relation to the presence and degree of maxillary sinus mucosal thickening.

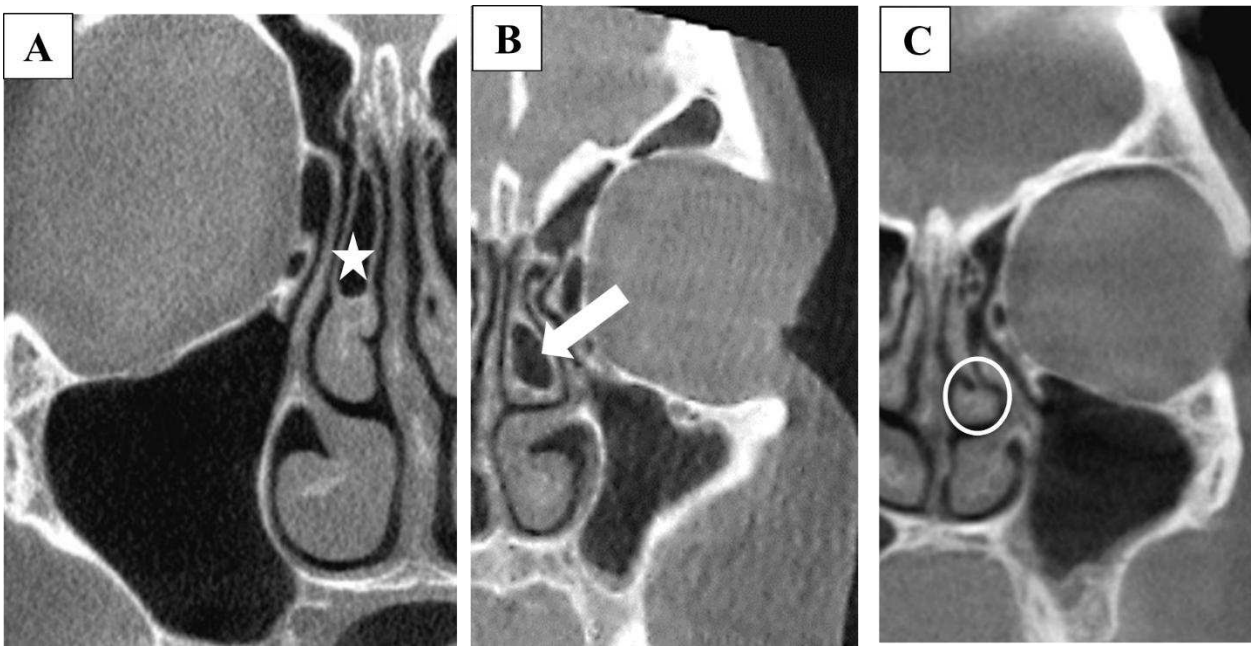


Figure 1: Cropped coronal CBCT showing (A) lamellar MT (asterisk), (B) concha bullosa MT (arrow), (C) paradoxical MT (circle).

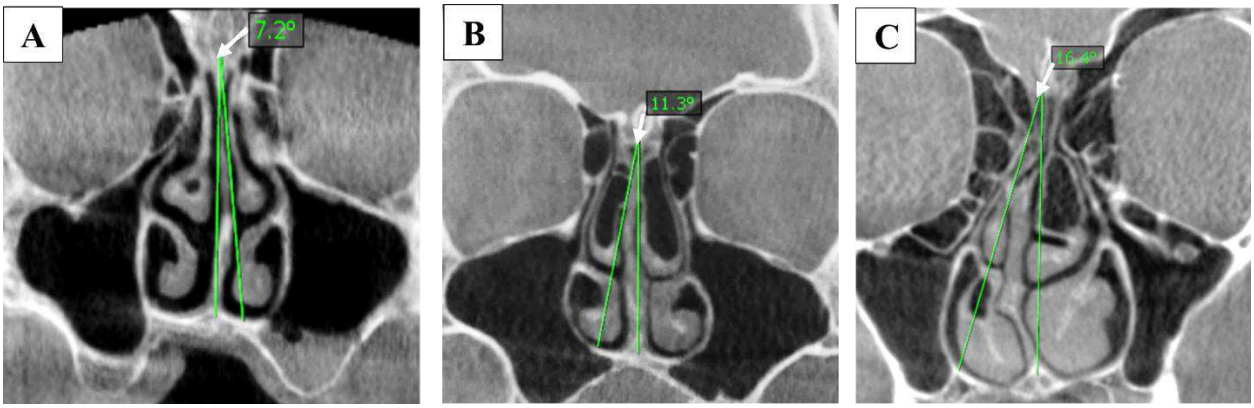


Figure 2: CBCT coronal cut showing the degree of NSD: (A) mild less than 9-degree, (B)moderate from 9 to 15 degree, (C) severe more than 15 degree.

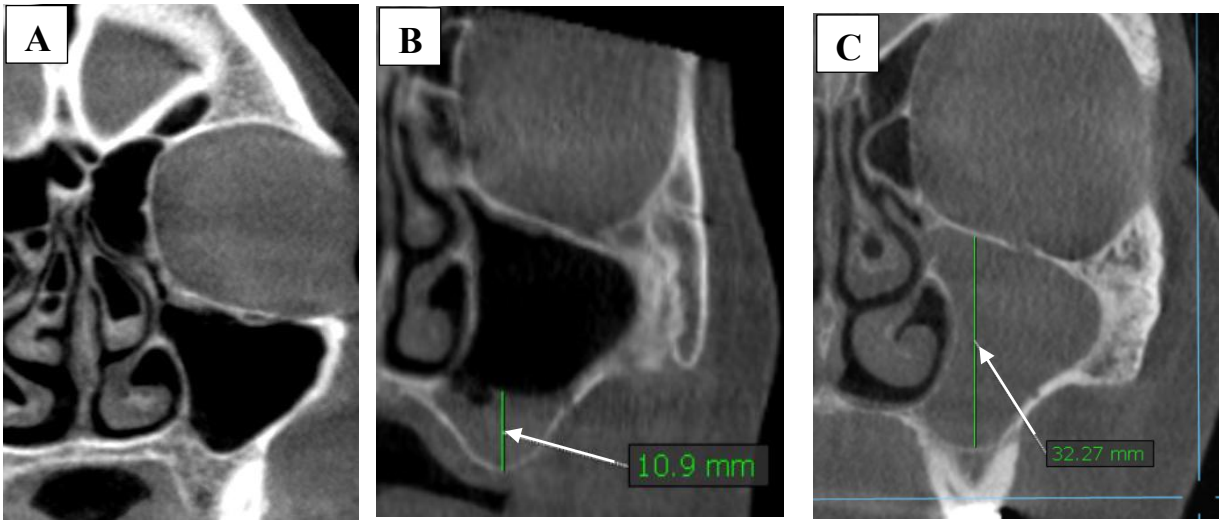


Figure 3: CBCT coronal cut showing normal maxillary sinus and no mucosal thickening grade 1 (A), hypoplastic maxillary sinus and sinus mucosal thickening grade 2 (B), severe mucosal thickening above 10 mm in left maxillary sinus grade 3 (C).

II.e. Statistical Analysis:

Statistical analysis was performed using SPSS program version 27, and Microsoft Excel 365. Descriptive statistics were used to summarize quantitative data as minimum, maximum, mean, and standard deviation values. Associations between categorical variables were assessed using the Chi-square test.

III. Results:

III.a. Evaluation the pneumatization of the MT:

The results revealed that concha bullosa of middle turbinate pneumatization (18.6% LT side, 20.6% RT side), lamellar (21.7%,19.4% RT side), least common paradoxical type with or without pneumatization (5.4% LT side,7.1%RT side) table 1.

Table 1: Comparison Between Right and Left Sides:

The pneumatization patterns of the MT was summarized in table 2. Pneumatization of the left side was present in 43.1% of subjects, while the right side showed a slightly higher prevalence of 44.6%. When considering the MT bilaterally, pneumatization was absent in 40% of individuals, present unilaterally in 32.3%, and present bilaterally in 27.7%. These findings

Variation	Left (N, %)	Right (N, %)
Concha bullosa	65 (18.6%)	72 (20.6%)
Lamellar concha bullosa	76 (21.7%)	68 (19.4%)
Paradoxical MT	19 (5.4%)	25 (7.1%)
Total variations	160 (45.7%)	165 (47.1%)

indicate that almost 60% of subjects showed middle turbinate pneumatization, predominantly unilateral.

Table 2: Radiological findings of middle turbinate:

		N	%
Pneumatization of left MT	Absent	199	56.9%
	Present	151	43.1%
Pneumatization of right MT	Absent	194	55.4%
	Present	156	44.6%
Pneumatization of middle turbinate	Absent	140	40%
	Unilateral	113	32.3%
	Bilateral	97	27.7%
Paradoxical of LT MT		19	5.4%
Paradoxical of RT MT		25	7.1%

III.b. Measurement of the NSD:

NSD measurements were presented in table 3. The deviation ranged from 3.00 ° to 24.10 °, with a mean of 9.50 ± 3.52 °.

Table 3: Nasal septum deviation angle:

	Min.	Max.	Mean	SD
Nasal septum deviation	3.00	24.10	9.50	3.52

The distribution of nasal septum deviation severity in the studied sample is illustrated in the table 4. Mild deviation was observed in 164 cases (46.9%), while the same proportion was recorded for moderate deviation (164 cases, 46.9%). In contrast, severe deviation was relatively uncommon, occurring in only 22 cases (6.2%).

Table 4: Degree of nasal septum deviation:

		N	%
Nasal septum deviation	Mild	164	46.9%
	Moderate	164	46.9%
	Severe	22	6.2%

III.c. Radiological Evaluation of Maxillary Sinusitis Severity Using Mucosal Thickening:
Radiological signs of maxillary sinusitis through mucosal thickening measurements were evaluated in table 5. The median mucosal thickening was 2.00 mm on the left and 2.25 mm on the right, with wide ranges extending up to 39–40 mm. Most cases were classified as grade 1 mucosal thickening (62 % left; 61.2% right), indicating mild sinus involvement. Grade 2 thickening was seen in approximately one-third of cases bilaterally (30.9 left; 29.4% right), whereas grade 3, representing more severe sinusitis, was the least frequent (7.1% left; 9.4% right).

Table 5: Radiological signs of maxillary sinusitis:

		Min.	Max.	Median	IQR*
Mucosal thickening LT		.40	39.61	2.00	1.22-4.40
Mucosal thickening RT		.40	40.63	2.25	1.30-5.90
		N		%	
Signs of sinusitis LT	Mucosal thickening grade 1	217		62%	
	Mucosal thickening grade 2	108		30.9%	
	Mucosal thickening grade 3	25		7.1%	
Signs of sinusitis RT	Mucosal thickening grade 1	214		61.2%	
	Mucosal thickening grade 2	103		29.4%	
	Mucosal thickening grade 3	33		9.4%	

* IQR = Interquartile Range

III.d. Radiological Correlation Between Ostiomeatal Complex Variations and Maxillary Sinusitis
The relationship between pneumatization of the right and left middle turbinate and the degree of right maxillary sinusitis is assessed in table 6. No statistically significant association was found ($p = 0.55$) in the right side and no significant relationship was observed ($p = 0.88$) in the left side. The proportion of pneumatization was similar across different grades of mucosal thickening, suggesting that concha bullosa on the right and left does not independently influence the severity of sinus disease in this cohort.
Table 6: Relation between radiological findings of middle turbinate and maxillary sinusitis (Right side& left side):

		Signs of sinusitis right						X2*	P value
		Mucosal thickening grade 1		Mucosal thickening grade 2		Mucosal thickening grade 3			
		N	%	N	%	N	%		
Pneumatization of right MT	Absent	114	53.3%	61	59.8%	18	54.5%	1.20	0.55
	Present	100	46.7%	41	40.2%	15	45.5%		
Pneumatization of left MT	Absent	121	55.8%	62	57.9%	15	60.0%	0.26	0.88
	Present	96	44.2%	45	42.1%	10	40.0%		

*Chi square test

Whether NSD was associated with sinusitis severity was presented in table 7. The mean deviation values were comparable across the three grades of sinusitis on both sides, with no statistically significant differences ($p = 0.38$ for right side, $p = 0.14$ for left). Although grade 3 sinusitis showed slightly lower mean deviation values, these differences were not significant.

Table 7: Relation between nasal septum deviation and maxillary sinusitis:

		Nasal septum deviation		F*	P value
		Mean	SD		
Signs of sinusitis right	Mucosal thickening grade 1	9.38	3.36	0.97	0.38
	Mucosal thickening grade 2	9.89	3.78		
	Mucosal thickening grade 3	9.11	3.68		
Signs of sinusitis left	Mucosal thickening grade 1	9.65	3.70	1.99	0.14
	Mucosal thickening grade 2	9.51	3.28		
	Mucosal thickening grade 3	8.17	2.59		

*One Way ANOVA test

The relationship between radiological types of the right and left uncinate process and the severity of maxillary sinusitis were examined in table 8. A statistically significant association was found at the right side ($p = 0.02$), particularly driven by the atelectatic type, which showed a markedly higher proportion of grade 3 mucosal thickening (30.3%). Other UP types (2, 3, blunt) were distributed across grades but without strong trends toward severe disease. Pneumatization of the UP showed no significant relationship with sinusitis severity ($p = 0.68$). These findings suggest that certain structural deformities of the UP especially atelectasis may predispose to more severe sinus pathology on the right side. Furthermore, the left side showed a highly significant relationship ($p < 0.001$). Specifically, atelectatic UP on the left demonstrated the strongest

association with advanced sinusitis, with 40% of cases of grade 3 mucosal thickening and 14% of grade 2 patients had atelectatic variant. In contrast, UP types 1–6 showed more typical distributions across mild-to-moderate sinusitis. Pneumatization of the left UP was not significantly related to sinusitis severity ($p = 0.27$). These findings confirm that left-sided UP atelectasis carries a substantial risk of severe sinus obstruction.

Table 8: Relation between radiological findings of uncinate process of ethmoidal bone and maxillary sinusitis (Right side & Left side):

		Signs of sinusitis right						X2*	P value
		Mucosal thickening grade 1		Mucosal thickening grade 2		Mucosal thickening grade 3			
		N	%	N	%	N	%		
Right UP	Type 1	17	7.9%	8	7.8%	3	9.1%	28.20	0.02
	Type 2	72	33.5%	29	28.4%	11	33.3%	FE	
	Type 3	24	11.2%	14	13.7%	5	15.2%		
	Type 4	14	6.5%	3	2.9%	0	0.0%		
	Type 5	11	5.1%	5	4.9%	1	3.0%		
	Type 6	14	6.5%	9	8.8%	0	0.0%		
	Atelectatic	12	5.6%	13	12.7%	10	30.3%		
	Blunt	51	23.7%	21	20.6%	3	9.1%		
Left UP	Type 1	15	6.9%	8	7.5%	0	0.0%	41.17	<0.001
	Type 2	75	34.4%	29	27.1%	8	32.0%	FE	
	Type 3	32	14.7%	11	10.3%	1	4.0%		
	Type 4	11	5.0%	7	6.5%	1	4.0%		
	Type 5	16	7.3%	7	6.5%	0	0.0%		
	Type 6	18	8.3%	3	2.8%	1	4.0%		
	Atelectatic	6	2.8%	15	14.0%	10	40.0%		
	Blunt	45	20.6%	27	25.2%	4	16.0%		
Pneumatization of right UP	Absent	160	74.8%	81	79.4%	25	75.8%	0.83	0.68
	Present	54	25.2%	21	20.6%	8	24.2%		
Pneumatization of left UP	Absent	165	76.0%	87	81.3%	22	88.0%	2.62	0.27
	Present	52	24.0%	20	18.7%	3	12.0%		

*Chi square test (FE: Fisher Exact)

Inter observer reliability:

Table 9: inter observer reliability statistical results of morphological and liner measurement:

	Kappa	95% confidence interval
Pneumatization of MT LT (Observer 2)	1.00	no discrepancies at all
Pneumatization of MT RT (Observer 2)	1.00	no discrepancies at all
Pneumatization of MT (Observer 2)	0.93	0.84-1.00
Signs of sinusitis LT (Observer 2)	0.76	0.53-0.99
Signs of sinusitis RT (Observer 2)	0.75	0.54-0.97

	Mean	SD	Intraclass correlation coefficient	95% CI
Nasal septum deviation			0.98	0.97-0.99
Observer 1	9.99	4.26		
Observer 2	10.08	4.16		
Mucosal thickening LT			0.69	0.43-0.85
Observer 1	4.13	6.65		
Observer 2	4.96	7.90		
Mucosal thickening RT			0.71	0.45-.0.89
Observer 1	4.10	5.67		
Observer 2	4.00	6.18		

Intra-observer reliability:

Table 10: intra observer reliability statistical results of morphological and liner measurement:

	Kappa	95% confidence interval
Pneumatization of MT LT (B)	1.00	no discrepancies at all
Pneumatization of MT RT (B)	1.00	no discrepancies at all
Pneumatization of MT (B)	0.93	0.83-1.00
Signs of sinusitis LT (B)	0.76	0.53-0.99
Signs of sinusitis RT (B)	0.79	0.57-0.95

	Mean	SD	Intraclass correlation coefficient	95% CI
Nasal septum deviation			0.98	0.96-0.99
Observer A	9.99	4.26		
Observer B	10.07	4.26		
Mucosal thickening LT			0.69	0.43-0.85
Observer A	4.13	6.65		
Observer B	4.93	7.92		
Mucosal thickening RT			0.71	0.45-.0.89
Observer A	4.10	5.67		
Observer B	4.02	6.21		

Inter- and intra-observer agreement ranged from moderate to excellent, depending on the evaluated variable in Table 9,10.

IV. Discussion:

Most radiologic investigations, reported to date, have utilized CT and have predominantly examined variations of the nasomaxillary complex within the context of otolaryngologic surgical practice. In contrast, the significance of these anatomical variations and their comprehensive assessment in dento-maxillofacial imaging have received comparatively limited attention(26–28).

In the present study, 350 CBCT scans obtained from individuals aged 12–72 years were included, comprising 147 males and 203 females. A total of 700 maxillary sides were evaluated. All scans were assessed on coronal CBCT images. Scans with a history of previous sinonasal surgery were excluded because surgical procedures may alter the normal anatomy of the nasomaxillary complex. Scans with a history of maxillofacial trauma were also excluded due to the possibility of anatomical distortion. Cases with tumors involving the nasomaxillary complex were excluded because these lesions may modify the normal anatomical structures. In addition, scans showing odontogenic maxillary sinusitis were excluded to ensure that only non-odontogenic maxillary sinusitis was investigated. Furthermore, CBCT scans in which the anatomical structures could not be adequately visualized were excluded, this was mainly attributed to motion artifacts (29)or pronounced mucosal thickening (30,31)obscuring the uncinate process and adjacent structures despite adjustments in image contrast and density, thereby preventing accurate radiographic assessment.

The present study specifically focused on the CBCT assessment of morphological variations of nasomaxillary complex in a sample of Egyptian population. Furthermore, the study investigated the prevalence of the nasomaxillary complex and their anatomical relationship to non-odontogenic mucosal thickening of the maxillary sinus.

IV.a. Middle Turbinate Variations:

Concerning the middle turbinate variations in this study, we determined, on the coronal CBCT section, the superior attachment of the uncinate process and the middle turbinate for pneumatization and classified accordingly. Variations of the middle turbinate were observed in 160 cases (45.7%) on the left side and 165 cases (47.1%) on the right side. On the left side, lamellar concha bullosa was the most frequent variant (21.7%), whereas on the right side, concha bullosa was more common (20.6%). So, the pneumatization of middle turbinate was a common anatomical variation in the studied population, while the paradoxical middle turbinate exhibited a considerably lower prevalence. There was no statistically significant association between middle turbinate pneumatization and maxillary sinusitis.

In this regard Calvo-Henríquez et al. (7) found lamellar cell pneumatization of the middle turbinate in 47.7% of 195 Spanish patients who had sinonasal CT scans. Similarly, El-Anwar et al. (8) reported that in an Egyptian asymptomatic adult population of 86 subjects (172 middle turbinates), pneumatization of the middle turbinate (concha bullosa) was the most common variation, observed in 88 sides (51.1%), while a paradoxical middle turbinate was identified in 58 sides (33.7%).

IV.b. Nasal Septal Deviation and Relationship Between Nasomaxillary Complex Variations and Non-Odontogenic Maxillary Sinusitis:

In the present study, mild and moderate nasal septal deviation constituted the majority of the examined cases, each identified in 164 cases (46.9%). In contrast, severe deviation was considerably less common, being detected in only 22 cases (6.2%). Regarding the association between nasal septal deviation severity and maxillary sinusitis severity, the current findings failed to demonstrate a statistically significant relationship. Similar mean deviation values were observed across the various grades of maxillary sinus mucosal thickening on both the right and left sides. While cases with grade 3 sinusitis showed slightly lower mean deviation values, the observed differences were not statistically significant.

Several studies have failed to find a statistically significant relationship between the presence of NSD and pneumatization of middle turbinate with maxillary sinus pathology, such as Smith et al. (32)conducted a CBCT study with 883 patients to investigate the prevalence and relationships between nasal septum deviation, concha bullosa, and sinus diseases. The study found that there

was no correlation between these anomalies and sinus diseases, with a prevalence of 67.5% septum deviation and 19.4% concha bullosa. Similarly, Demirel et al. (33) reported nasal septum deviation in 64.5% of the 200 evaluated patients and 47% had Concha bullosa of middle turbinate with no statistically significant association with maxillary sinus diseases.

Similarly, Kim et al. (34) , in a Korean population, found no significant correlation between CB and ipsilateral ethmoid and maxillary sinusitis, although seeing CB at a rate of 32.7%. Likewise, Yalçın et al. (35), in a CBCT-based study on a Turkish population, reported a concha bullosa prevalence of 31.3% and found no statistically significant association between concha bullosa and maxillary sinus pathology. In contrast Fadda et al. (36) , in an Italian population, reported a concha bullosa prevalence of 49.3% and identified a significant association between bilateral concha bullosa and bilateral maxillary sinusitis.

However, this observation disagrees with several other investigations, Orlandi (37) identified a significant relationship between increasing septal deviation angles and the prevalence of rhinosinusitis, particularly when the septal deviation angle exceeded 10°, Gancer et al. (38)sought to ascertain the potential contribution of nasal septal deviation to the volume of the maxillary sinus and its connection to the onset of maxillary sinusitis, İncebeyaz et al. (39) reported that the maxillary sinus volume and sinusitis were not significantly impacted by mild or moderate septal deviations, while they were significantly impacted by extreme deviations. Moreover, structural discrepancies influencing sinus ventilation and drainage have been linked to the onset of rhinosinusitis (39).

Concerning the association between maxillary sinusitis and differences in the superior attachment of the uncinate process. Both the left side ($p < 0.001$) and the right side ($p = 0.02$) showed significant connections according to statistical analysis. These results lend credence to the theory that anatomical differences in the superior attachment of the uncinate process may modify the osteomeatal complex's structure and impact the ventilation and drainage of the maxillary sinus, hence raising the risk of sinus pathology. Although there was no significant correlation between the severity of sinusitis and the pneumatization of the UP ($p = 0.68$), some structural abnormalities of the UP, particularly atelectasis, may be a risk factor for more severe sinus pathology.

Notably, atelectasis of the uncinate process appeared to be associated with more severe maxillary sinus pathology, accounting for 40% of the studied cases, followed by Type 2 superior attachment showing 32% and the remaining attachment patterns. Furthermore, additional radiographic manifestations of maxillary sinusitis, such as air–fluid levels and maxillary sinus wall sclerosis, were observed alongside mucosal thickening in a limited subset of patients ($n = 31$). Within this subgroup, atelectatic uncinate processes were identified in 41.9% of cases, while Type 2 attachments constituted 51.6%. The relatively high proportion of Type 2 cases may be explained by its predominance as the most common superior attachment pattern in the studied population.

This study has limitations that should be acknowledged. First, the lack of clinical data and symptom correlation limited the assessment of the clinical significance of the observed radiographic finding. Second, Potential confounding factors, such as smoking status, allergic conditions, and other medical comorbidities, were not available for analysis.

Further multicenter studies with larger sample sizes are warranted to confirm the present findings across different populations. Additionally, future investigations may explore the potential application of artificial intelligence-assisted image analysis in the evaluation of sinonasal anatomical variations, particularly with respect to improving diagnostic consistency and facilitating large-scale radiological assessments.

V. Conclusions:

Among the anatomical differences of the nasomaxillary complex assessed with CBCT, superior attachment and morphological variants of the uncinate process showed the strongest and statistically significant correlation with maxillary sinus mucosal thickening. Pneumatization of the middle turbinate and deviation of the nasal septum were noted in the study sample; however, their correlations with the severity of mucosal thickness did not achieve statistical significance. These results indicate that the morphology of the uncinate process within the nasomaxillary complex may serve as a more significant radiographic marker for non-odontogenic alterations in the maxillary sinus compared to abnormalities in the middle turbinate or nasal septum. CBCT proved to be an effective imaging modality for evaluating these anatomical relationships.

Declarations:

Human Ethics and Consent to Participate: The study was conducted in accordance with the ethical standards of the Declaration of Helsinki and was approved by the Ethics Committee of the Faculty of Dentistry, Ain Shams University (Approval No. FDASU–RecEm012524). The requirement for informed consent was waived by the Ethics Committee due to the retrospective nature of the study and the use of anonymized patient data.

Consent for publication: Not applicable.

Consent to Participate: The Ethics Committee of the Faculty of Dentistry at Ain Shams University waived the necessity for informed consent due to the study's retrospective design and use of anonymized data.

Data Availability: The datasets created and analyzed during the current investigation are accessible from the corresponding author on reasonable request.

Competing Interests: The authors have declared that they have no competing interests.

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Authors' contributions:

Mariam khaled Farouk Algressy: Conceptualization, study design, data collection, image assessment, data analysis, and manuscript preparation.

Fatma Mostafa El-Badawy: Supervision, methodology, interpretation of findings, and critical revision of the manuscript.

Naglaa Fathallah Ahmed: Supervision, radiographic assessment, interpretation of findings, and critical revision of the manuscript. All authors read and approved the final manuscript.

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List of abbreviations	
CBCT	Cone beam computed tomography
CT	computed tomography
OMC	osteomeatal complex
MT	middle turbinate
PMT	paradoxical middle turbinate
NS	nasal septum
UP	uncinate process
EADMFR	European Academy of Dentomaxillofacial Radiology
MT	middle turbinate
RT	right
LT	left

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