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Anatomical variations of the maxillary sinuses: A cross-sectional study

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Abstract. Anatomical variations of the maxillary sinus have important clinical implications, yet factors influencing maxillary sinus volume (MSV) remain debated. The present study evaluated MSV and related anatomical variations in an Iraqi population using multi-slice computed tomography. Sinus dimensions and volume were measured using the Radiant DICOM viewer, and variations including infraorbital nerve (ION) protrusion, septation, Haller cells, and hypoplasia were assessed. Maxillary sinus asymmetry was common. Males demonstrated significantly larger sinus volumes on both sides compared with females ($P<0.001$). Age had no significant effect on right MSV ($P=0.123$), whereas left MSV varied across age groups ($P=0.025$). A key finding was the strong association between ION protrusion and increased MSV bilaterally ($P<0.001$). Septations, Haller cells, and hypoplasia occurred infrequently but remained relevant anatomical considerations. Overall, the present study revealed substantial anatomical variability in the maxillary sinus and highlighted the importance of preoperative imaging, particularly when ION protrusion is present, to support safe and effective surgical planning.

Introduction

The anatomy of the nasal cavities and paranasal sinuses exhibits substantial variability, making it one of the most diverse regions in the human body. Given their intricate three-dimensional structure and numerous morphological variations, a comprehensive understanding of these anatomical features is essential for sinus surgeons (1). The maxillary sinus, pyramid-shaped and the largest of the paranasal sinuses, is situated directly behind the anterior bony surface of the midface and is encased by bone structures (2). This sinus was first described in 1651 by the English anatomist Nathaniel Highmore (3). Its development initiates in the 10th week of intrauterine life, marked by primary extension, a phase in which air fills the cavity to increase its volume. At the 20th week of pregnancy, secondary pneumatization occurs, allowing the maxillary sinus to expand into the maxilla, reaching a volume of approximately 6-8 cm^3 at birth. Thereafter, it continues to expand laterally and inferiorly during two rapid growth phases: The first from birth to 3 years and the second from 7 to 12 years. This progressive inferior expansion correlates with the alveolar process invasion, influenced by the eruption of permanent teeth, ultimately extending 4 to 5 mm below the nasal floor and achieving an average volume of 15 cm^3 by age 18 to 20 (4). Anatomical variations in the maxillary sinuses are acknowledged to possess significant clinical implications, although their distinctive presentation and prevalence can vary widely (3). The literature remains controversial regarding the factors directly associated with the maxillary sinus volume (MSV), primarily due to the challenges in tracking its development in individuals without facial bone abnormalities. Additionally, measuring the sinus volume in clinical practice is complicated by its position within the middle third of the face (4). Despite these, anatomical differences among ethnic groups challenge the use of a standardized evaluation method. A cross-sectional study showed that Chinese individuals have significantly larger sinuses than Yemenis (5). A multi-ethnic review also reported ethnic differences in sinonasal anatomical variants, supporting that maxillary sinus anatomy varies by demographic background (6). Although some scholars from Middle Eastern countries, such as Saudi Arabia, have characterized maxillary sinus anatomy, comprehensive regional evaluations remain limited. Overall, reviews of sinonasal variation report considerable population differences, emphasizing that data from the Middle Eastern population are relatively sparse compared with other ethnicities (7). Advanced three-dimensional imaging techniques, such as computed tomography (CT) and cone beam CT (CBCT), are the preferred methods for visualizing the maxillary sinus and diagnosing sinus pathologies before surgical intervention (1,8). The present study used multi-slice CT scans to evaluate anatomical variations in the maxillary sinuses and associated factors in the Sulaymaniyah population.

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Key words: paranasal sinuses, computed tomography, Haller cells, infraorbital nerve, infraorbital canal, anatomy

Patients and methods

Study design and ethical considerations. This retrospective cross-sectional study was conducted on 283 patients who visited Smart Health Tower (Sulaymaniyah, Iraq) for paranasal sinus imaging over one year. The study was approved (approval no. 62-6/1/2024) by the Research Ethics Committee of the University of Sulaimani, College of Medicine (Sulaymaniyah, Iraq). Written informed consent was obtained from each participant before enrollment and for the publication of this study and any accompanying images.

Data collection and anatomical assessment. Due to the hazardous radiation exposure, the sample was obtained from the hospital registry using a non-randomized sampling method. A total of 283 multi-slice CT images were acquired, of which 227 were included, while 56 were excluded based on predetermined eligibility criteria. The thickness of the multi-slice CT scans ranged from 1.0 to 1.5 mm. All measurements and interpretations of the CT files were conducted using the RadiAnt DICOM Viewer 2023.1 (Medixant; https://www.radiantviewer.com/) by a single expert radiologist. Each sinus was assessed for variability in terms of anteroposterior diameter, axial diameter, cranio-caudal diameter, and volume, calculated using the ellipsoid approximation formula (Figs. 1 and 2). Additionally, the presence and location of infraorbital nerve (ION) protrusion, septation, Haller cells, and hypoplasia were evaluated. The maximum diameter was determined following a thorough review of all slices. Subsequently, two-dimensional measurements were converted to three-dimensional volume by multiplying them and applying a correction factor of 0.53. Furthermore, the percent difference formula was employed, where the absolute difference was divided by the larger of the two volumes and multiplied by 100. A result yielding a difference of 10% or more was classified as a significant asymmetry. Maxillary sinus hypoplasia was diagnosed by comparing the length or width of the sinus with that of the adjacent orbit. If either parameter of the maxillary sinus was half or less than the corresponding orbit parameter, it indicated hypoplasia. While sagittal reconstruction was not utilized for analyzing lengths and volumes, it was employed for qualitative assessments to identify and exclude abnormalities or variations (Fig. 3).

Eligibility criteria. The eligibility criteria for the study were restricted to patients aged 14 years and older, with visible pneumatization, and complete visualization of the inferior maxillary bone, including the superior alveolar process. Cases with any visible abnormalities or pathologies were excluded, such as absent or inadequate maxillary sinus pneumatization, incomplete visualization of the maxillary sinus, any maxillary sinus pathology affecting volume (mucosal thickening > 2 mm, retention cyst, polyps, air fluid levels, chronic sinusitis, space-occupying lesions), dental or odontogenic conditions altering sinus anatomy, history of sinus surgery, history of maxillofacial or craniofacial trauma, and developmental or structural craniofacial abnormalities. The references in this paper were verified for authenticity using reputable blacklists (9).

Statistical analysis. The data were exported to an Excel sheet and entered into the Statistical Package for Social Sciences (SPSS) version 27 (IBM Corp.). Categorical data were analyzed using the Chi-square test, while numerical data were evaluated with the independent samples t-test and one-way ANOVA. The results were presented as frequencies, percentages, means with standard deviations, and medians with ranges. $P<0.05$ was considered to indicate a statistically significant difference.

Results

Baseline characteristics. The sample population included 128 males (56.4%) and 99 females (43.6%) with a median age of 39 years (range, 15 to 90 years). Regarding sinus volume, 20.2% of females exhibited a larger right sinus, while 79.8% had a smaller right sinus. For the left sinus, 24.0% of females had a larger sinus, and 76.0% had a smaller one. Overall, sinus symmetry was observed in 37.4% of cases, while 62.6% were asymmetrical. Among asymmetrical cases, 58.5% were male and 41.5% were female. Maxillary sinus septations were found in 19.8% of patients, with a greater prevalence among males (57.8%) than females (42.2%). In terms of laterality, 42.2% of septations were bilateral, 35.6% were right-sided, and 22.2% were left-sided. ION protrusions were observed in 27.3% of cases, with a higher occurrence in males (61.3%) than females (38.7%). Most protrusions were bilateral (64.5%), followed by left-sided (19.4%) and right-sided (16.1%). An accessory maxillary ostium (AMO) was present in 48.0% of participants, with 57.8% occurring in males and 42.2% in females. The ostium was primarily bilateral (56%), with 28.4% on the right and 15.6% on the left. Haller cells were identified in 10.1% of cases, with a higher prevalence in males (60.9%) than in females (39.1%). Of the Haller cells, 13.0% were bilateral, 52.2% were on the right side, and 34.8% were on the left. Sinus hypoplasia was found in two cases (1%) (Table I).

Right MSV by sex and age. Males generally exhibited a larger mean sinus volume than females across most age ranges. The mean volume for the 14-29 age group was 21.90 cc in males vs. 16.72 cc in females ($P<0.001$). This trend persisted, with significant differences also observed in the 50-59 and >60 age groups, where males had mean volumes of 19.58 and 20.17 cc, respectively, compared with 12.33 and 12.95 cc in females ($P=0.004$ and $P=0.002$, respectively). Overall, the mean sinus volume was significantly larger in males (20.12 cc) than in females (15.60 cc) ($P<0.001$). For the anteroposterior dimension of the maxillary sinus, males had an overall mean of 3.76 cm compared with 3.57 cm in females ($P<0.001$). The cranio-caudal dimension was also significantly greater in males (3.68 cm) than in females (3.29 cm) ($P<0.001$). Significant sex differences in cranio-caudal length were observed across several age groups, including 14-29 ($P=0.015$), 30-39 ($P=0.002$), and >60 ($P=0.002$). Transverse measurements also revealed a larger mean dimension in males (2.68 cm) compared to females (2.43 cm) ($P<0.001$; Table II).

Left MSV by sex and age. In the 14-29 age group, the mean volume was 23.16 cc in males and 17.71 cc in females ($P<0.001$). Significant differences were also observed in the 50-59 and >60 age groups, with males having mean volumes

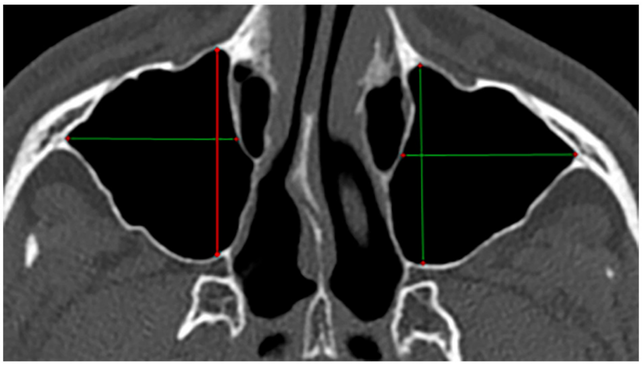

Figure 1. Anteroposterior and transverse parameters on an axial view.

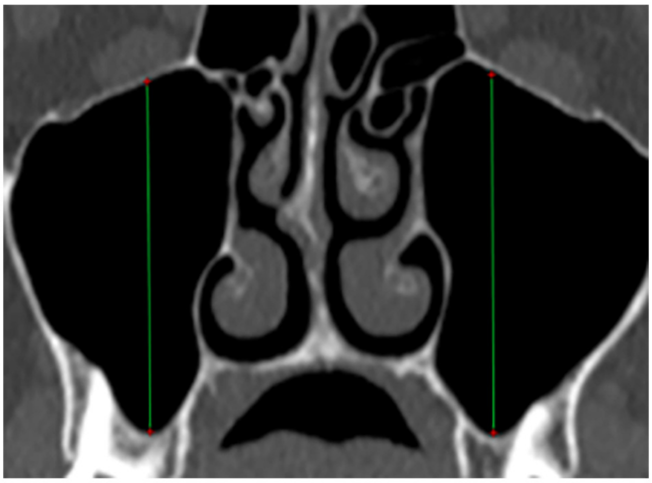

Figure 2. Cranio-caudal (asterisk) parameter on a coronal view.

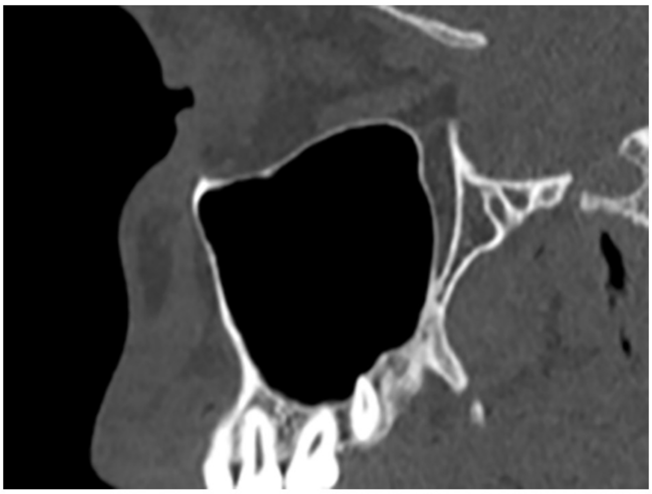

Figure 3. Sagittal reconstruction of the left maxillary sinus.

of 19.17 and 19.92 cc, respectively, compared with 13.66 and 13.83 cc in females (P=0.037 and P=0.011, respectively). Overall, the left sinus volume was significantly greater in males (21.08 cc) than in females (16.40 cc; P<0.001). The left maxillary sinus dimensions also exhibited sex differences. In general, the mean anteroposterior dimension was significantly

Table I. Baseline characteristics of the study.

Variables	Frequency/ Percentage
Age, median (range), year	39 (15-90)
Sex	
Male	128 (56.4%)
Female	99 (43.6%)
Sinus volume	
Right sinus	
Larger in females	20 (20.2%)
Smaller in females	79 (79.8%)
Left sinus	
Larger in females	24 (24.0%)
Smaller in females	75 (76.0%)
Sinus symmetry	
Symmetrical	85 (37.4%)
Asymmetrical	142 (62.6%)
Male	83 (58.5%)
Female	59 (41.5%)
Septations	
Yes	45 (19.8%)
No	182 (80.2%)
Septations by sex	
Male	26 (57.8%)
Female	19 (42.2%)
Septations laterality	
Bilateral	19 (42.2%)
Right	16 (35.6%)
Left	10 (22.2%)
Infraorbital nerve protrusions	
Yes	62 (27.3%)
No	165 (72.7%)
Infraorbital nerve protrusions by gender	
Male	38 (61.3%)
Female	24 (38.7%)
Infraorbital nerve protrusions laterality	
Bilateral	40 (64.5%)
Right	10 (16.1%)
Left	12 (19.4%)
Accessory maxillary ostium	
Yes	109 (48.0%)
No	118 (52.0%)
Accessory maxillary ostium by sex	
Male	63 (57.8%)
Female	46 (42.2%)
Accessory maxillary ostium laterality	
Bilateral	61 (56.0%)
Right	31 (28.4%)
Left	17 (15.6%)
Haller cells	
Yes	23 (10.1%)
No	204 (89.9%)

Table I. Continued.

Variables	Frequency/ Percentage
Haller cells by sex	
Male	14 (60.9%)
Female	9 (39.1%)
Haller cells laterality	
Bilateral	3 (13.0%)
Right	12 (52.2%)
Left	8 (34.8%)
Sinus hypoplasia	
Yes	2 (1.0%)
No	225 (99.0%)

larger in males (3.80 cm) than in females (3.61 cm; P<0.001), with a notable difference in the 14-29 and 50-59 age groups (P=0.005 and P=0.002, respectively). Cranio-caudal measurements were also significantly greater in males (3.81 cm) than in females (3.35 cm; P<0.001). For the transverse dimension, males had a mean of 2.67 cm compared with 2.46 cm in females (P<0.001) (Table III).

Comparison of the right and left maxillary sinuses. There was no significant difference in the right MSV across age groups (P=0.123), while the left MSV varied significantly (P=0.025). Regarding the anteroposterior, craniocaudal, and transverse dimensions, the right maxillary sinus showed no significant differences across age groups in the first two dimensions; however, a significant difference was observed in the transverse dimension (P=0.037). For the left maxillary sinus, significant differences were noted in both the anteroposterior and transverse dimensions among age groups (P=0.006 and P=0.026, respectively) (Table IV). Additionally, ION protrusion was significantly associated with increasing MSV on both the right and left sides (P<0.001) (Table V).

Discussion

A comprehensive understanding of the anatomical variations and pathologies of the maxillary sinus is essential for clinical practice in dentistry, maxillofacial surgery, and otolaryngology. Various imaging techniques, including CT and CBCT, have been used to assess the nasal cavity and maxillary sinuses. Conventional radiographs offer only a two-dimensional view of anatomical structures. By contrast, CT and CBCT provide valuable insights for imaging and identifying anatomical variations within the bony structures of the paranasal sinuses (2,3). MSV and sinus dimensions may vary by age and between individuals. Additionally, even within the same individual, there may be variations between the right and left sinus parameters (2). The relatively high prevalence of maxillary sinus asymmetry (62.6%) and the variability in other parameters in this study may be influenced by several anatomical, developmental, and environmental factors. Craniofacial morphological variations, particularly vertical skeletal growth patterns, have been shown to affect sinus dimensions and contribute to side-to-side differences in MSV (10). Ethnic and population-specific variability further contributes to these differences, as studies in other populations report wide variation in sinus asymmetry prevalence, depending on methodology and population (5,6,11). Developmental factors, including differential pneumatization and sinus remodeling influenced by dental status, skeletal growth, and sinonasal anatomy, may also play a role (12). Environmental and functional influences, such as chronic sinonasal inflammation or differences in mastication patterns, can contribute to asymmetric sinus development over time (13). Finally, methodological factors, including imaging modality, slice orientation, and the threshold used to define asymmetry, may partly explain differences in prevalence across studies. The prevalence of AMO in the present study (~48%) has important anatomical and clinical implications. AMO has been consistently associated with impaired mucociliary clearance, mucus recirculation, and a higher risk of recurrent or chronic maxillary sinusitis (14). Generally, AMO prevalence ranges from 35-56% and is significantly associated with abnormal maxillary sinus mucosal changes, such as mucosal thickening or natural-ostium obstruction (15). This pathophysiological mechanism suggests that AMO may facilitate mucus recirculation between the accessory and natural ostia, predisposing the sinus to chronic inflammation and recurrent sinusitis (16). In our study population, the high prevalence of AMO underscores the importance of careful preoperative imaging assessment for ENT surgeons, radiologists, and dental/maxillofacial clinicians to minimize procedural complications and anticipate potential sinus drainage issues.

In the present cohort, maxillary sinus septations were identified in approximately one-fifth of patients (~20%). This finding aligns with reported prevalence rates from CBCT and CT studies, which range from 21 to 25.6% of sinus segments and 25-37% of individuals, depending on the population and imaging method employed (17,18). Anatomically, these septa comprise bony ridges that divide the sinus cavity, often oriented bucco-palatally and located in the middle region, which complicates surgical access (18). Clinically, the presence of septa significantly increases the risk of perforating the Schneiderian membrane during sinus lift procedures. A meta-analysis across 1,865 patients (2,168 sinus lifts) found an odds ratio of ~4.03 for perforation when septa were present, compared with sinuses without septa (19).

Congenital maxillary sinus hypoplasia was identified in 1% of the cases in this study, consistent with the low prevalence reported in the literature (5.65%) (20). It is clinically significant because it may mimic chronic maxillary sinusitis, present with nonspecific symptoms, or lead to diagnostic confusion on routine imaging. In addition, the altered anatomy may complicate endoscopic sinus surgery, increase the risk of orbital penetration, and affect surgical planning (20). Therefore, even though its prevalence is low, awareness of this variation is essential for accurate radiologic interpretation and safe surgical management.

Certain studies indicated a significant association between age and MSV, noting that MSV decreases with age (21,22). By contrast, others reported no significant differences between the right and left MSV values and MSV with

Table II. Comparison of sex regarding right maxillary sinus volume based on age groups.

A, Right sinus parameters

	Male		Female		
Age groups	Mean volume (cc)	Standard deviation	Mean volume (cc)	Standard deviation	P-value
14-29	21.90	7.10	16.72	3.52	<0.001
30-39	18.83	6.81	15.57	5.02	0.070
40-49	18.82	5.93	17.78	5.04	0.570
50-59	19.58	6.21	12.33	5.06	0.004
>60	20.17	7.47	12.95	5.97	0.002
Overall	20.12	6.79	15.60	5.06	<0.001

B, Anteroposterior dimension

	Male		Female		
Age groups	Mean diameter (cm)	Standard deviation	Mean diameter (cm)	Standard deviation	P-value
14-29	3.88	0.33	3.58	0.34	<0.001
30-39	3.73	0.45	3.66	0.31	0.540
40-49	3.64	0.28	3.71	0.40	0.560
50-59	3.83	0.27	3.32	0.46	0.010
>60	3.66	0.57	3.39	0.69	0.200
Overall	3.76	0.39	3.57	0.45	<0.001

C, Cranio-caudal dimension

	Male		Female		
Age groups	Mean diameter (cm)	Standard deviation	Mean diameter (cm)	Standard deviation	P-value
14-29	3.75	0.61	3.46	0.34	0.015
30-39	3.64	0.57	3.28	0.47	0.002
40-49	3.61	0.62	3.37	0.52	0.170
50-59	3.60	0.50	3.08	0.47	0.018
>60	3.75	0.72	2.99	0.69	0.002
Overall	3.68	0.60	3.29	0.51	<0.001

D, Transverse dimension

	Male		Female		
Age groups	Mean diameter (cm)	Standard deviation	Mean diameter (cm)	Standard deviation	P-value
14-29	2.81	0.33	2.58	0.32	<0.001
30-39	2.52	0.48	2.39	0.40	0.340
40-49	2.63	0.38	2.55	0.47	0.560
50-59	2.61	0.50	2.23	0.42	0.054
>60	2.72	0.60	2.26	0.48	0.010
Overall	2.68	0.51	2.43	0.44	<0.001

cc, cubic centimeter.

age (21,23,24). Sex differences in MSV have also been explored. Aşantoğrol and Coşgunarslan (2) and Al-Rawi *et al* (23) observed that males had greater maxillary sinus width, height, and length than females, with statistically significant differences. Conversely, Demir *et al* (25) and Lessa *et al* (4) reported no significant correlation between MSV and sex. Despite these

Table III. Comparison of sex regarding left maxillary sinus volume based on age groups.

A, Left sinus parameters

	Male		Female		
Age groups	Mean volume (cc)	Standard deviation	Mean volume (cc)	Standard deviation	P-value
14-29	23.16	6.81	17.71	5.06	<0.001
30-39	19.80	8.24	16.12	5.04	0.074
40-49	21.14	6.59	18.29	7.32	0.195
50-59	19.17	5.48	13.66	6.09	0.037
>60	19.92	7.64	13.83	6.07	0.011
Overall	21.08	7.08	16.40	5.93	<0.001

B, Anteroposterior dimension

	Male		Female		
Age groups	Mean diameter (cm)	Standard deviation	Mean diameter (cm)	Standard deviation	P-value
14-29	3.92	0.36	3.66	0.38	0.004
30-39	3.75	0.50	3.70	0.30	0.626
40-49	3.78	0.26	3.81	0.32	0.751
50-59	3.80	0.35	3.31	0.33	0.002
>60	3.66	0.40	3.35	0.71	0.126
Overall	3.80	0.38	3.61	0.45	<0.001

C, Cranio-caudal dimension

	Male		Female		
Age groups	Mean diameter (cm)	Standard deviation	Mean diameter (cm)	Standard deviation	P-value
14-29	3.90	0.54	3.46	0.33	<0.001
30-39	3.74	0.59	3.35	0.40	0.011
40-49	4.85	0.52	3.45	0.62	0.029
50-59	3.66	0.49	3.22	0.63	0.091
>60	3.75	0.64	3.12	0.65	0.005
Overall	3.81	0.55	3.35	0.50	<0.001

D, Transverse dimension

	Male		Female		
Age groups	Mean diameter (cm)	Standard deviation	Mean diameter (cm)	Standard deviation	P-value
14-29	2.80	0.37	2.59	0.39	0.023
30-39	2.54	0.52	2.40	0.42	0.331
40-49	2.67	0.40	2.52	0.51	0.284
50-59	2.56	0.46	2.29	0.45	0.154
>60	2.65	0.64	2.31	0.53	0.081
Overall	2.67	0.47	2.46	0.46	<0.001

cc, cubic centimeter.

findings, numerous studies support that MSV values are generally higher in males than in females (21,23). In the present study, the right MSV did not vary significantly with age, whereas the left MSV showed differences across age groups. Concerning sex, the MSV on both sides was significantly higher in males than in females, with this difference evident across age categories.

Table IV. Comparison of right and left maxillary sinus volumes based on age groups.

A, Sinus parameters

	Right maxillary sinus			Left maxillary sinus		
Age groups	Mean volume (cc)	Standard deviation	P-value	Mean volume (cc)	Standard deviation	P-value
14-29	19.67	6.35	0.123	20.82	6.66	0.025
30-39	17.16	6.12		17.92	6.97	
40-49	18.43	5.54		19.98	6.96	
50-59	17.16	6.73		17.34	6.17	
>60	16.85	7.65		17.13	7.52	

B, Anteroposterior dimension

	Right maxillary sinus			Left maxillary sinus		
Age groups	Mean diameter (cm)	Standard deviation	P-value	Mean diameter (cm)	Standard deviation	P-value
14-29	3.75	0.37	0.149	3.81	0.39	0.006
30-39	3.70	0.38		3.72	0.40	
40-49	3.67	0.33		3.79	0.28	
50-59	3.66	0.41		3.64	0.41	
>60	3.53	0.63		3.52	0.57	

C, Cranio-caudal dimension

	Right maxillary sinus			Left maxillary sinus		
Age groups	Mean diameter (cm)	Standard deviation	P-value	Mean diameter (cm)	Standard deviation	P-value
14-29	3.63	0.53	0.300	3.71	0.51	0.140
30-39	3.46	0.55		3.54	0.54	
40-49	3.51	0.59		3.69	0.59	
50-59	3.43	0.54		3.52	0.57	
>60	3.40	0.79		3.46	0.71	

D, Transverse dimension

	Right maxillary sinus			Left maxillary sinus		
Age groups	Mean diameter (cm)	Standard deviation	P-value	Mean diameter (cm)	Standard deviation	P-value
14-29	2.71	0.39	0.037	2.71	0.39	0.026
30-39	2.44	0.44		2.47	0.47	
40-49	2.58	0.46		2.61	0.45	
50-59	2.49	0.58		2.47	0.47	
>60	2.52	0.66		2.49	0.61	

cc, cubic centimeter.

Accurate identification of bony septa is essential to enhance the safety of surgical procedures, particularly sinus lift surgeries and implant placements, as septa have been associated with an increased risk of sinus membrane perforation and thinner sinus mucosa. This risk is heightened when the septa are arranged longitudinally or are incomplete, as these configurations can complicate membrane elevation compared with a transverse arrangement (4). In terms of anatomical variations, previous studies found no association between the presence of septa and MSV. However, significant increases in the maxillary sinus width on both the left and right sides were noted when septa were present (2,21). The prevalence of bony

Table V. Effect of ION protrusions on maxillary sinus volumes.

Variable	Right sinus volume			Left sinus volume		
	Mean (cc)	Standard deviation	P-value	Mean (cc)	Standard deviation	P-value
With ION protrusion	20.93	5.62	<0.001	21.20	6.18	<0.001
Without ION protrusion	17.36	6.52		18.39	7.12	

ION, infraorbital nerve; cc, cubic centimeter.

septa within the maxillary sinus has been reported to range from 9.5 to 70%, varying according to the studied population and diagnostic modality used (26). Lessa *et al* (4) observed that 47% of maxillary sinuses presented with bony septa, although no significant difference was noted in MSV related to the presence of septa. Şimşek Kaya *et al* (27) identified septa in 32.9% of 228 evaluated sinuses, while Asan *et al* (3) reported a prevalence rate of 24%, with septa more commonly located on the right side. Sex differences in septa prevalence have been inconsistent in the literature. A study found a higher prevalence of septa among females, with no association between septa and age or dental status (28). Conversely, studies by Koymen *et al* (29) and Hong *et al* (30) reported a male predominance in septa presence. This increased occurrence in males has been postulated to relate to the typically higher mean maximum bite force in males than females (29,30). In the present study, maxillary sinus septation was identified in 45 cases (19.8%), comprising 26 males (57.8%) and 19 females (42.2%). Bilateral septation was the most common in 19 cases (42.2%).

Haller cells, or infra-orbital ethmoid cells, are air-filled cavities inferolateral to the ethmoidal bulla (3). These cells can increase susceptibility to sinus pathologies by accelerating inflammation, complicating sinus surgery, and contributing to conditions such as rhinosinusitis. Infection of Haller cells can lead to mucosal swelling, which restricts secretion transport and creates a cycle that may contribute to unilateral orbital cellulitis (3). Prevalence rates of Haller cells vary widely in the literature, with reports ranging from 4.7 to 45.1% or 5.5 to 45.9% (31,32). Asan *et al* (3) observed Haller cells in 15.3% of samples, identifying them as the second most significant anatomical variation. Although there was no significant difference in prevalence between sexes, a higher occurrence was noted on the right side (3). Chaudhari *et al* (32) found a prevalence of 10% (30 out of 300 individuals), with 18 males and 12 females, yielding a male-to-female ratio of 3:2. Conversely, Ahmad *et al* (33) reported a notably higher prevalence of 38.2%, with a higher occurrence among females (32). Regarding laterality, Chaudhari *et al* (32) reported that Haller cells appeared bilaterally in 16 cases and unilaterally in 14, suggesting a tendency for bilateral occurrence. This finding contrasts with a previous study that reported a predominantly unilateral presentation of Haller cells (34). The current study identified Haller cells in 23 cases (10.1%), comprising 14 males and 9 females. The majority of these cases were unilateral (87%) and predominantly located on the right side (52.2%), consistent with the findings of Ramaswamy *et al* (34) and Asan *et al* (3). The most prevalent anatomical variation observed was sinus asymmetry, identified in 142 cases (62.6%). Conversely, the presence of Haller cells was the second least common variation. This finding contrasts with the study by Asan *et al* (3), who identified Haller cells as the second most frequent anatomical variation.

Lantos *et al* (35) defined infraorbital canal (IOC) protrusion as occurring when the entire 360° circumference of the IOC wall lacked contact with a maxillary sinus wall on at least one axial CT image. Although reported prevalence rates for ION protrusion range from 8 to 35%, there is no standardized definition for protrusion despite efforts to establish a classification system (35). In their study, Lantos *et al* (35) observed a 10.8% prevalence of IOC protrusion into the maxillary sinus, with a bilateral protrusion rate of 5.6% (34). Eiid *et al* (36) found that the IOC most frequently presented as the typical confined type, detected in 78.1% of sinuses, while the suspended (or protruded) variant was identified in 14.6% of cases. They emphasized that IOC protrusion, though not uncommon, requires heightened caution from surgeons utilizing the maxillary sinuses as access points, particularly in the upper lateral areas of the sinus (36). In the present study, ION protrusion into the maxillary sinus was present in 62 cases (27.3%), with bilateral protrusions in 40 cases (17.6%). On both sides, ION protrusion was significantly associated with increased MSV. The observed association between ION protrusion and increased MSV in our study has important anatomical and clinical implications. Previous volumetric research demonstrated that individuals with a 'descending' or protruding IOC Type 3 consistently exhibit significantly larger MSVs, suggesting that extensive sinus pneumatization may progressively encompass or suspend the canal within the sinus cavity. Since the developmental trajectory of the ION canal is established prenatally, whereas maxillary sinus pneumatization continues through adolescence and adulthood, this relationship supports the concept that ION protrusion is likely a pneumatization-driven variant rather than an isolated anomaly (37). Clinically, larger sinuses have been associated with a higher prevalence of canal exposure or 'suspension' into the sinus lumen, reported in ~11% of cases in large CT-based series, underscoring the risk of iatrogenic nerve injury during endoscopic sinus surgery, dental implant placement, or transmaxillary procedures (35). Therefore, these findings reinforce the importance of preoperative imaging, particularly volumetric assessment, in patients exhibiting large maxillary sinuses, as the likelihood of encountering a protruding or vulnerable IOC is increased. This relationship also highlights the need for future research to routinely incorporate sinus volume when evaluating ION canal variants to improve anatomical understanding and surgical planning.

The small sample size, non-random sampling, no multiple comparison analysis, lack of assessment of interobserver reliability, the use of ellipsoid volume estimates, and the data being collected from only a single center are significant limitations of this study that may affect the generalizability of the findings.

In conclusion, anatomical variations of the maxillary sinus were common within the study population, with asymmetry present in 62.6%. The maxillary sinus was revealed to be significantly larger in males than in females, exhibiting notable differences in dimensions and volume. Additionally, this study revealed an association between ION protrusion and sinus volume; specifically, sinuses with protruded ION tended to have larger volumes. These findings suggest the potential necessity for preoperative assessments utilizing CT scans or other three-dimensional imaging techniques.

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Availability of data and materials

The data generated in the present study may be requested from the corresponding author.

Authors' contributions

SHT was the major contributor to the conception of the study, as well as to the literature search for related studies. SHT and RS were involved in the literature review and the writing of the manuscript. YF and BS were involved in the literature review, the design of the study, the critical revision of the manuscript, and the processing of the tables. SHT and RS acquired the data, as well as performed the data analysis and interpretation. In addition, SHT and RS confirm the authenticity of all the raw data. All authors have read and approved the final manuscript.

Ethics approval and consent to participate

The study was approved (approval no 62-6/1/2024) by the Research Ethics Committee of the University of Sulaimani, College of Medicine (Sulaymaniyah, Iraq). Written informed consent was obtained from each participant before enrollment.

Patient consent for publication

Written informed consent was obtained from the patients for the publication of this study and any accompanying images.

Competing interests

The authors declare that they have no competing interests.

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