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Prevalence and Morphometrics of Haller Cells in Iraqis, and Their Association with Sinusitis and Sino-Nasal Anatomical Variants of Interest Using High-Resolution Computed Tomography

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Abstract

Background: Haller cells (HCs) possess radiological and clinical significance because of their close relationship to the ostiomeatal complex and orbital floor. We aim to determine the prevalence of HCs in an Iraqi population, assess their morphometry, and evaluate their associations with selected sino-nasal anatomical variants, particularly concha bullosa (CB) and Onodi cells (OCs), as well as with sinusitis. **Methods:** In this retrospective study, high-resolution CT scans were obtained from Baghdad Medical City. Images were reviewed using RadiAnt DICOM Viewer version 2025.2. Haller cells were assessed for laterality and measured on coronal CT for length, width, and sectional area. Data were analyzed in IBM SPSS Statistics version 27. **Results:** Of 121 assessed CT scans, 103 were included in the final analysis. HCs were found in 36.9% of cases, most commonly as unilateral right-sided cells. Strong positive correlations were observed among HC morphometrics, especially between length and sectional area on both sides (left: $\rho = 0.920$, $p < 0.001$; right: $\rho = 0.876$, $p < 0.001$). No significant side- or sex-based differences were found concerning any of the morphometrics. Further, no significant associations were found between HCs and sex, nasal septum deviation (NSD), OCs, maxillary sinusitis, or sphenoid sinusitis. Nonetheless, the association between HCs and CB possessed borderline significance (OR = 2.37, 95% CI: 0.86–6.57; $p = 0.091$). **Conclusions:** Haller cells were the least common of the evaluated sino-nasal variants and showed generally symmetrical morphometrics despite more frequent right-sided unilateral occurrence. They were not significantly associated with sex, NSD, OCs, or sinusitis, although the borderline association with CB warrants further study.

Keywords: computed tomography; ethmoid sinus; ethmoidal air cells; Haller cells; image-based morphometry; infraorbital ethmoidal air cells; morphometric analysis; orbital floor; ostiomeatal unit; sino-nasal anatomy

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1. Introduction

The infraorbital ethmoidal air cells, also known as Haller cells (HCs), are anterior ethmoidal pneumatizations that extend along the medial orbital floor into the roof of the maxillary sinus; they lie immediately superior to the maxillary antral infundibulum. From an anatomical perspective, HCs are located at a transitional zone between the ethmoid labyrinth and the maxillary sinus; they are closely related to crucial anatomical structures of the ostiomeatal unit (OMU), particularly the maxillary infundibulum, which represents

the natural drainage pathway of the maxillary sinus. Haller cells may also lie in proximity to the infraorbital canal, thereby possessing an important surgical relationship along the orbital floor. Morphologically, HCs can exhibit substantial variation, ranging from small slit-like pockets to larger well-pneumatized air cells; these may differ in size, shape, and laterality [1–3].

Haller cells represent a well-recognized sino-nasal anatomical variant; however, their prevalence is generally lower than that of more common variants such as concha bullosa (CB). Published evidence indicates that their frequency varies across populations. Al-Abri et al. (2014) reported a prevalence of 24% in an Omani population [3], while Göçmen et al. (2015) found a prevalence of 19.3% in a Turkish population from Istanbul [4]. Kaya (2024) also reported a prevalence of 37% in Turkish individuals from the Eastern Anatolia Region [5]. Such variation emphasizes the need for population-specific radiological investigations of HCs, including those in the Middle East.

Because of the anatomical variability of HCs and their relatively concealed location, they are best evaluated radiologically by high-resolution computed tomography (CT); coronal and axial bone-window reconstructions allow accurate delineation of their osseous boundaries and spatial relationship to adjacent sino-nasal structures [4]. Coronal high-resolution (slice thickness ≤ 1 mm) CT images are valuable for demonstrating their inferior extension; HCs extend from the ethmoid labyrinth toward the orbital floor and maxillary sinus roof. In contrast, axial sections complement this assessment by clarifying their anteroposterior extent. Therefore, systematic radiological identification of HCs mandates careful documentation of their presence, side (laterality), dimensions (morphometrics), and relation to neighboring anatomical landmarks; the purpose is to ensure standardized characterization and permit reliable comparisons across studies.

The clinical importance of HCs arises primarily from their location adjacent to the maxillary infundibulum; even relatively small pneumatized cells could contribute to narrowing of the infundibular passage or the natural ostium of the maxillary sinus, and, therefore, reduction in the functional drainage space of the maxillary sinus. Such alterations may impair mucociliary clearance and sinus ventilation; these have been implicated as possible predisposing factors for recurrent maxillary sinusitis or chronic rhinosinusitis (CRS) in susceptible individuals. Nonetheless, the extent of this association remains inconclusive; the potential contribution of HCs to ostiomeatal obstruction attracts anatomical and radiological interest, particularly when they coexist with other sino-nasal variations (such as concha bullosa) that may further compromise drainage pathways [1,3–5].

In addition to their possible role in sino-nasal inflammatory disease, HCs can have surgical implications. Their close relationship to the orbital floor, maxillary sinus roof, infraorbital canal, and ostiomeatal complex makes them important landmarks during endoscopic sinus surgery; these include procedures involving the maxillary ostium, uncinate process, ethmoidal region, or orbit. Failure to recognize or characterize HCs preoperatively may increase the risk of incomplete disease resolution, misinterpretation of radiological findings, or iatrogenic injury to adjacent anatomical structures. Further, because of their anatomical proximity to the infraorbital nerve and peri-orbital compartment, HCs may also be relevant in the interpretation of specific peri-orbital or mid-facial symptoms [3–5].

Given that the prevalence, morphometric features, and possible clinical implications of HCs vary across different populations and that they may coexist with other sino-nasal anatomical variants such as CB, accurate radiological identification and standardized morphometric assessment are essential for defining their anatomical significance. Detailed evaluation of HCs on high-resolution CT can provide useful insights into normal sino-nasal anatomy, population-based anatomical variation, and their potential relationship with sinusitis, especially maxillary sinusitis, and sino-nasal anatomical variants of interest.

Although HCs have been widely investigated, evidence concerning their prevalence, morphometry, and related sino-nasal associations in the Iraqi population remains limited. In addition, variability in radiological identification and morphometry methods due to heterogeneous studies has limited inter-study comparability and has rendered crucial population-specific data insufficiently defined. The present study aims to determine the prevalence of HCs in an Iraqi cohort using high-resolution CT, assess their morphometrics, evaluate their relationship with specific sino-nasal anatomical variants, and examine their potential association with sinusitis, especially maxillary sinusitis.

2. Materials and Methods

2.1. Research Ethics

Ethical approval for the study was obtained from the Institutional Review Board of the College of Medicine, University of Baghdad (Ref. No. 1436; 26 November 2024). All radiological images were treated confidentially, and all datasets were anonymized prior to analysis, with no personal identifiers retained.

2.2. Study Design and Level of Evidence

The present study is a retrospective observational study based on high-resolution CT images of the paranasal sinuses (PNS). According to the Oxford Center for Evidence-Based Medicine, this study design corresponds to Level 4 evidence [6].

2.3. Inclusion and Exclusion Criteria

The study sample included adult Iraqi patients who had retrospective high-resolution CT scans of the PNS performed at the Radiology Unit of Baghdad Medical City. The cohort consisted of two groups: a study group with radiologically confirmed CRS and a control group of individuals with no radiological evidence of sino-nasal disease. In the control group, CT scans had been obtained for non-sinonasal clinical indications, and the PNS were reported as normal on imaging. Only high-resolution CT examinations (slice thickness ≤ 1 mm), reconstructed using a bone algorithm and of sufficient image quality for morphometric analysis, were included. The scans were required to provide adequate spatial resolution for reliable morphometry.

Paranasal sinus CT scans were excluded if image quality was inadequate, including low spatial resolution, inappropriate slice thickness, or incomplete visualization of the anatomical structures of interest. Additional exclusion criteria included radiological evidence of mid-facial trauma, previous sino-nasal or cranio-facial surgery, macroscopic sino-nasal neoplasms, active sino-nasal infection at the time of imaging other than CRS, pediatric age, and cranio-facial syndromes.

2.4. Imaging Technique and Software

Computed tomography images were obtained from patients who underwent CT examination at Baghdad Medical City between September 2025 and February 2026. A total of 121 CT scans were collected, anonymized, and stored on two personal computers equipped with secure backup systems and licensed antivirus software, comprising 12.1 GB of radiological imaging data.

Paranasal sinus CT was performed with a one-millimeter (1 mm) slice thickness. Scans were acquired using a Siemens SOMATOM Definition AS CT scanner (device ID CTAWP67140; Siemens Healthcare GmbH, Forchheim, Germany) at Al-Shaheed Ghazi Hospital for Surgical Specialties, Baghdad Medical City. All CT images were accessed in Digital Imaging and Communications in Medicine (DICOM) format and evaluated using RadiAnt DICOM Viewer software version 2025.2 [7].

Orthogonal multiplanar reconstructions (2D MPRs) were generated in RadiAnt DICOM Viewer software version 2025.2 to produce axial, coronal, and sagittal images for morphometric analysis and to aid in distinguishing HCs from adjacent anatomical structures. In addition, three-dimensional volume rendering (3D VR) was performed for exploratory assessment of the spatial anatomical relationships. Nonetheless, all morphometric measurements were derived strictly from 2D MPRs.

2.5. Haller Cell Morphometrics

Haller cells were evaluated for laterality (right, left, or bilateral) and quantified on coronal CT reconstructions (Figure 1). Linear dimensions and the sectional area were measured on the slice showing the largest section of HCs. Linear measurements were rounded to the nearest 0.1 mm, whereas area measurements were rounded to the nearest 0.01 cm^2. The assessed morphometric parameters included the maximal length, maximal width, and maximal sectional area of HCs.

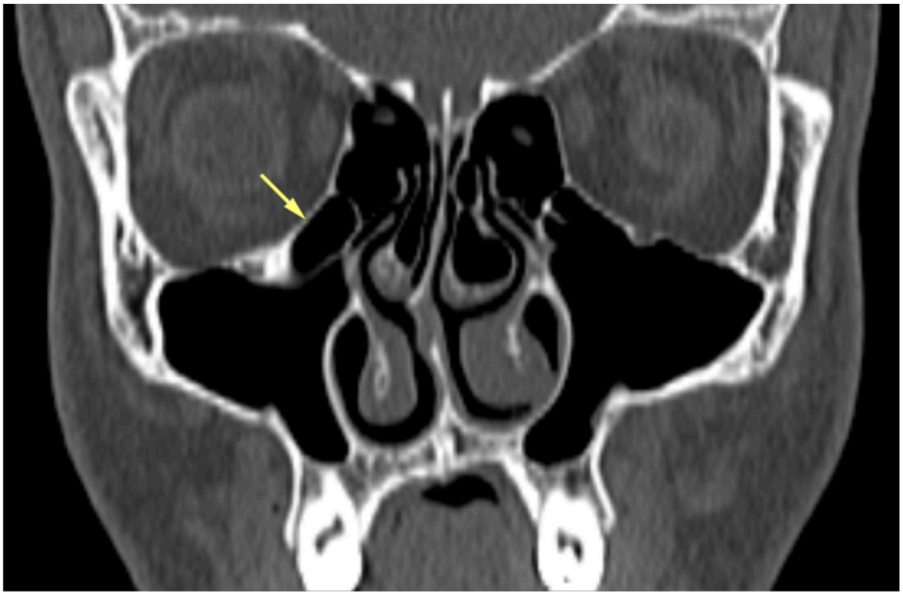


Figure 1. Coronal CT image showing right-sided HCs in an 18-year-old Iraqi male.

2.6. Data Analysis and Statistical Methods

Raw CT data were tabulated in Microsoft Excel 2016 and then imported into IBM SPSS Statistics version 27 for statistical analysis. Descriptive and inferential statistics were applied using both parametric and nonparametric tests, according to data distribution and normality testing (Shapiro–Wilk test). Continuous variables were summarized as mean ± standard deviation (SD) with 95% confidence intervals (CIs) for normally distributed data and as median with interquartile range (IQR) for non-normally distributed data.

Associations between categorical variables were assessed using the Chi-square test of independence or Fisher's exact test, as applicable. Bivariate correlations were performed to generate correlation matrices. Effect sizes and 95% confidence intervals were reported where relevant. Statistical significance was set at a two-sided alpha level of 0.05 (p-value < 0.05), and statistical power was set at 80% ($\beta = 0.20$).

3. Results

3.1. The Study Sample

A total of 121 cases were initially assessed (Figure 2), of which 103 were included in the final statistical analysis ($n = 103$). The excluded cases were one duplicate entry

(female, 57 years), one elderly outlier (male, 78 years), three minors (males, <18 years), one case with suboptimal CT acquisition (male, 23 years), and one with severe nasal cavity deformity (male, 21 years), likely secondary to prior trauma or surgery. The remaining eleven exclusions (10 males, 1 female) demonstrated extensive rhinosinusitis with effusion (inflammatory secretions) filling the PNS and overflowing into the nasal cavity, obliterating turbinates, meatuses, and other anatomical landmarks.

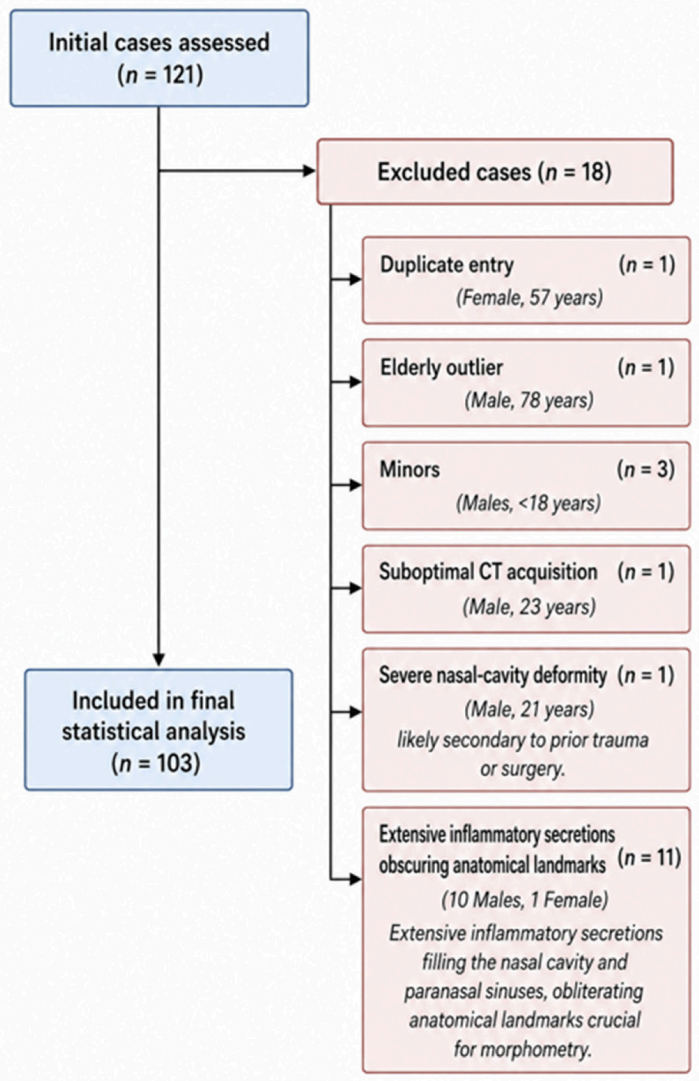


Figure 2. Flow diagram of case selection and reasons for exclusion.

3.2. Descriptive Statistics and Normality Testing

The study sample included 103 Iraqi individuals (n = 103) identified from the Radiology Unit records between 22 September 2025 and 16 February 2026. Participants were predominantly in the fourth decade of life (median, 32 years; IQR, 23–42 years). Males accounted for 55 cases (53.4%) and females for 48 cases (46.6%).

Concerning age and the morphometric parameters, the distribution of the data was assessed using normality tests. Age did not show a normal distribution. Regarding HCs morphometrics, data distribution was assessed for the right and left HCs measurements. On the right side, width and length were consistent with a normal distribution, whereas the sectional area did not follow a normal distribution. On the left side, all three measurements (width, length, and area) were consistent with a normal distribution.

3.3. Prevalence and Laterality of Haller Cells and Other Variants

Haller cells were detected in 38 of 103 cases (36.9%). Among the total sample, unilateral right HCs were the most common pattern, observed in 17 cases (16.5%), followed by bilateral involvement in 11 cases (10.7%) and unilateral left involvement in 10 cases (9.7%). Within the 38 positive cases, unilateral right distribution accounted for 44.7%, followed by bilateral distribution at 28.9% and unilateral left distribution at 26.3%.

Concerning other sino-nasal variants of interest, CB was identified in 77 of 103 cases (74.8%). In the total sample, bilateral CB was the most frequent laterality pattern, observed in 37 cases (35.9%), followed by unilateral right CB in 28 cases (27.2%) and unilateral left CB in 12 cases (11.7%). Among CB-positive cases only, bilateral involvement accounted for 48.1%, followed by unilateral right CB at 36.4% and unilateral left CB at 15.6%.

Regarding Onodi cells (OCs), they were identified in 57 participants (55.3%). Prevalence was relatively comparable between sexes, occurring in 33 males (60.0%) and 24 females (50.0%). Bilateral OCs were the most common pattern (25, 24.3%), followed by unilateral right OCs (20, 19.4%), unilateral left OCs (10, 9.7%), and central OCs (2, 1.9%).

3.4. Prevalence of Nasal Septum Deviation

Nasal septum deviation (NSD) was identified in 98 of 103 cases (95.1%). In the total sample, left-sided NSD was slightly more common than right-sided NSD, occurring in 50 cases (48.5%) and 48 cases (46.6%), respectively. Among NSD-positive cases only, left-sided deviation accounted for 51.0%, while right-sided deviation accounted for 49.0%.

Regarding severity, mild NSD was observed in 22 cases, corresponding to 21.4% of the total sample and 22.4% of NSD-positive cases, whereas both moderate and severe NSD were each identified in 38 cases, representing 36.9% of the total sample and 38.8% of NSD-positive cases. Concerning the magnitude of NSD, the median value was 12.8° (IQR, 8.4–16.8°); moderate and severe grades of NSD were prevalent among Iraqis.

3.5. Prevalence of Sinusitis

Maxillary sinusitis was more frequent than sphenoid sinusitis, affecting 41 (39.8%) and 21 (20.4%) individuals, respectively. Among cases of maxillary sinusitis, bilateral involvement was most common (28, 27.2%), followed by unilateral right (10, 9.7%) and unilateral left involvement (3, 2.9%). Similarly, bilateral sphenoid sinusitis was the predominant pattern (9, 8.7%), whereas unilateral right and unilateral left sphenoid sinusitis were each observed in 6 cases (5.8%).

3.6. Haller Cell Morphometrics

Morphometrics (Table 1) showed that right-sided HCs had a median width of 4.9 mm (IQR, 3.3–5.7), median length of 7.9 mm (IQR, 5.9–10.5), and median sectional area of 0.28 cm^2 (IQR, 0.16–0.44), whereas left-sided HCs had a median width of 4.6 mm (IQR, 3.5–5.6), median length of 7.0 mm (IQR, 6.1–9.7), and median sectional area of 0.27 cm^2 (IQR, 0.17–0.43).

Table 1. Comparison of Haller cell morphometrics by laterality.

Parameter	Median Values		IQR Values	
	Right-Sided HCs	Left-Sided HCs	Right-Sided HCs	Left-Sided HCs
Width	4.9	4.6	3.3–5.7	3.5–5.6
Length	7.9	7.0	5.9–10.5	6.1–9.7
Sectional area	0.28	0.27	0.16–0.44	0.17–0.43

HCs, Haller cells; IQR, interquartile range.

3.7. Statistical Analysis and Hypothesis Testing

Bivariate Spearman correlations (Table 2) demonstrated several significant positive associations among HCs morphometric parameters. The strongest correlation was observed between left-sided HCs length and sectional area (ρ = 0.920, $p < 0.001$), followed by right-sided HCs length and sectional area (ρ = 0.876, $p < 0.001$), left-sided width and sectional area (ρ = 0.833, $p < 0.001$), and right-sided width and sectional area (ρ = 0.765, $p < 0.001$), all of which were strong correlations. In contrast, the associations between left-sided HCs width and length (ρ = 0.673, $p < 0.001$) and right-sided width and length (ρ = 0.494, $p = 0.010$) were moderate positive correlations.

Table 2. Bivariate Spearman correlation matrix of Haller cell morphometrics.

		HCs (Right, Width)	HCs (Right, Length)	HCs (Right, Area)	HCs (Left, Width)	HCs (Left, Length)	HCs (Left, Area)
HCs (right, width)	Coefficient	--					
	p-value	.					
	N	26					
HCs (right, length)	Coefficient	0.494	--				
	p-value	0.010	.				
	N	26	26				
HCs (right, area)	Coefficient	0.765	0.876	--			
	p-value	<0.001	<0.001	.			
	N	26	26	26			
HCs (left, width)	Coefficient	−0.036	0.318	0.455	--		
	p-value	0.915	0.340	0.160	.		
	N	11	11	11	22		
HCs (left, length)	Coefficient	0.173	0.364	0.582	0.673	--	
	p-value	0.612	0.272	0.060	0.001	.	
	N	11	11	11	22	22	
HCs (left, area)	Coefficient	0.009	0.391	0.536	0.833	0.920	--
	p-value	0.979	0.235	0.089	<0.001	<0.001	.
	N	11	11	11	22	22	22

HCs, Haller cells.

Although right-sided HCs showed slightly greater median values for width and length, no statistically significant laterality-based differences were found for width ($p = 0.964$), length ($p = 0.600$), or sectional area ($p = 0.909$). On another note, there were no statistically significant sex-based differences in HCs' morphometric parameters on either side. For right-sided HCs, no significant differences were observed for width ($p = 0.683$), length ($p = 0.384$), or sectional area ($p = 0.760$) between males and females. Similarly, for left-sided HCs, there were no significant sex-based differences in width ($p = 0.948$), length ($p = 0.695$), or sectional area ($p = 0.845$).

There was no association between the presence of HCs and sex ($\chi^2 = 0.489$, df = 1, $p = 0.484$), NSD ($\chi^2 = 1.991$, df = 1, $p = 0.158$), or OCs ($\chi^2 = 0.695$, df = 1, $p = 0.405$) (Figure 3). Likewise, no statistically significant association was found between HCs and CB at the 5% significance level ($\chi^2 = 2.852$, df = 1, $p = 0.091$); however, this result approached significance at the 10% level, suggesting a potential association between the two variants (OR = 2.37, 95% CI: 0.86–6.57). On another note, regarding the association with sinusitis, there was no association between the presence of HCs and either maxillary ($\chi^2 = 0.787$, df = 1, $p = 0.375$) or sphenoid sinusitis ($\chi^2 = 1.939$, df = 1, $p = 0.164$) (Figure 4).

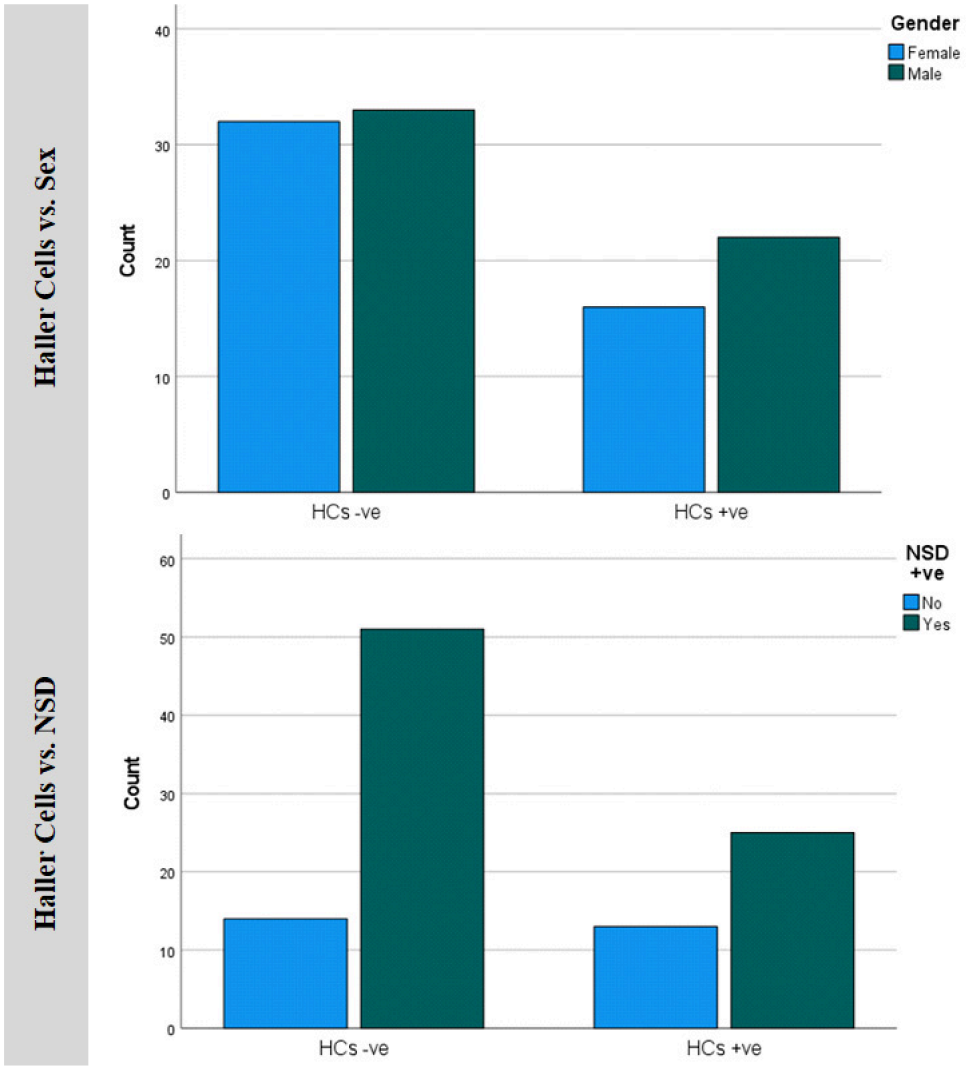


Figure 3. Association of Haller cells with sex and nasal septum deviation. HCs, Haller cells; NSD, nasal septum deviation.

In summary, HCs were identified in 36.9% of cases, with unilateral right-sided HCs representing the most prevalent pattern. Morphometric analysis showed comparable right- and left-sided HCs dimensions, with no significant laterality-based differences in width, length, or sectional area. Significant positive correlations were observed among HCs morphometric parameters, strongest between length and sectional area on both sides, while width–length correlations were weaker. Further, HCs morphometry did not differ significantly between males and females. No significant associations were found between the presence of HCs and sex, NSD, OCs, maxillary sinusitis, or sphenoid sinusitis; however, the association between HCs and CB had borderline significance, suggesting a possible co-existence.

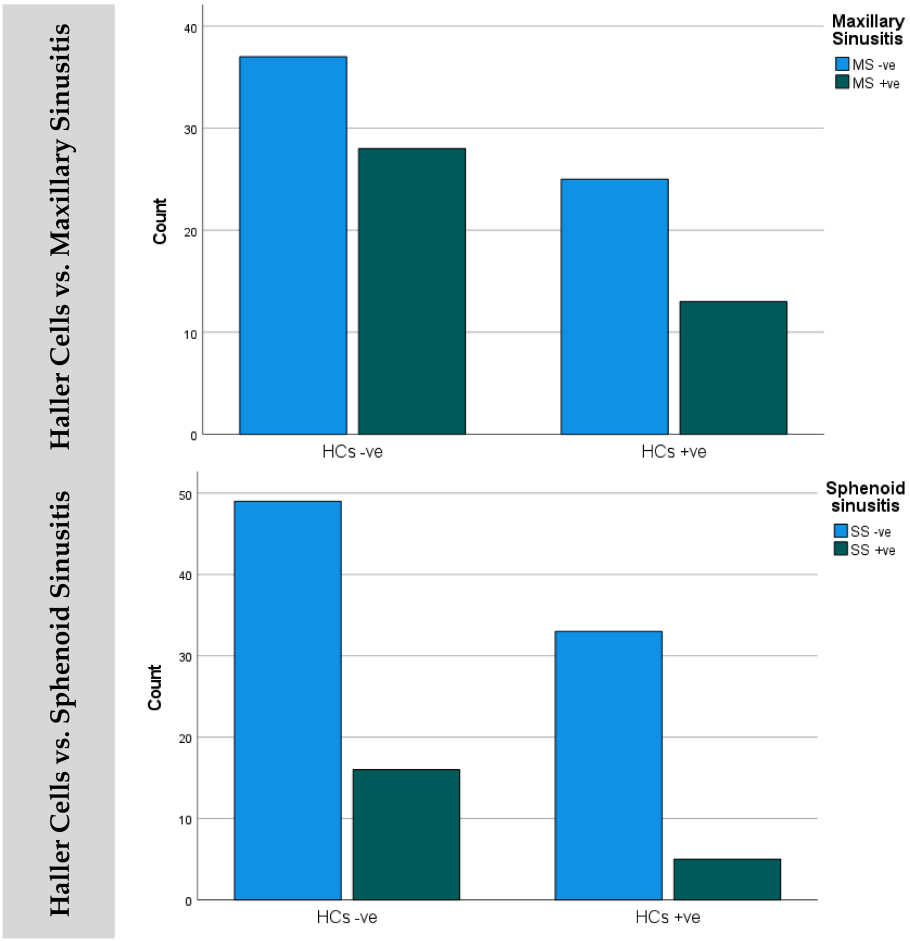


Figure 4. Association of Haller cells with sinusitis.

4. Discussion

4.1. Key Findings and Interpretations

Regarding HCs, the present study found a prevalence of 36.9%, indicating that they are the least common sino-nasal anatomical variant in the Iraqi population compared with CB and OCs. Unilateral right-sided HCs were the most frequent, followed by bilateral and unilateral left-sided HCs. The predominance of right-sided unilateral occurrence might reflect natural anatomical asymmetry rather than a clinically meaningful laterality tendency, particularly because the morphometric findings did not reveal significant differences between right- and left-sided HCs.

Morphometric analysis further showed that HCs on both sides had comparable dimensions. Although right-sided HCs exhibited slightly higher median width and length values than left-sided HCs, these differences were not statistically significant; this suggests that, when HCs are present, their size characteristics are generally symmetrical at the population level despite differences in laterality of occurrence.

An additional important finding was the strong positive relationship between HCs' dimensions, particularly between length and sectional area on both sides, which indicates that an increase in HCs' sectional area closely accompanies an increase in its length. Width also correlated positively with sectional area, while the association between width and length was weaker; this implies that HCs' enlargement may not occur uniformly in all dimensions. In practical terms, this may mean that the sectional area is influenced more strongly by expansion, or pneumatization, along the infra-orbital border.

No significant sex-based differences were identified concerning the presence or morphometric features of HCs, which suggests that HCs prevalence and size are likely independent of sex-related cranio-facial variation in the studied Iraqi population. Similarly, the lack of significant associations between HCs and NSD, OCs, or maxillary sinusitis suggests that HCs may occur largely as an isolated anatomical entity rather than as part of a broader pattern of sino-nasal structural variations or inflammatory sinus disease.

Although the association between HCs and CB did not reach statistical significance at the 5% level, the borderline significance and the odds ratio (>1) suggest a possible tendency toward co-occurrence; this might point to a shared developmental mechanism or anatomical predisposition between these two variants. However, this finding should be interpreted cautiously and regarded as hypothesis-generating rather than conclusive.

Overall, the findings indicate that HCs represent a relatively less common sino-nasal anatomical variant with generally symmetric morphometric characteristics and limited association with other sino-nasal variants or sinusitis. Their clinical importance in the studied Iraqi population appears to lie more in their prevalence and anatomical presence than in any demonstrated relationship with sinusitis or other variants of interest. Nonetheless, the borderline association with CB warrants further evaluation in larger studies with representative sampling to clarify whether a genuine anatomical association exists.

4.2. Discussion of the Literature

The overall prevalence of Haller cells (HCs) in the present study was 36.9%, which falls within the broad range reported in the literature. It is higher than the prevalence reported in CT-based studies by Leunig et al. (2008) (16%) and Ragab et al. (2025) (13.7%) [8,9], but lower than the CBCT-based estimate of 56.7% reported by Moshfeghi et al. (2023) [10], highlighting the influence of imaging modality, image resolution, and diagnostic criteria on prevalence estimates. Population-specific variation may also contribute to these differences, as evidenced by reported prevalences of 24% in an Omani population [3], 19.3% in a Turkish population from Istanbul [5], and 37% in individuals from the Eastern Anatolia region of Türkiye [4]. The relatively high prevalence observed in the present Iraqi cohort further emphasizes the importance of population-specific radiological investigations, particularly within the Middle East, and suggests that genetic or ethnic factors may partly underlie regional differences in HCs prevalence.

Unilateral right-sided HCs were the most frequent pattern in the present Iraqi study, followed by bilateral and unilateral left-sided HCs, which is broadly in line with Ragab et al. (2025) [9], who also reported unilateral right-sided HCs more often than unilateral left-sided HCs; however, bilateral cases were the most common in their series. On another note, Moshfeghi et al. (2023) found unilateral HCs to be more common than bilateral HCs [10], supporting the tendency toward asymmetric presentation.

Significant positive correlations were identified among the morphometric parameters of HCs, particularly between length and sectional area, and to a lesser extent, between width and sectional area; the former phenomenon is anatomically plausible, as an increase in the linear dimensions of HCs would be expected to correspond to a greater area.

The former morphometric finding suggests that the shape of HCs is primarily determined by their longitudinal dimension, indicating an oval configuration with the long axis oriented parallel to the infraorbital floor. Although this specific spatial relationship has rarely been stated explicitly in the literature, it is consistent with previous studies describing HCs as predominantly oval or ovoid in shape, including Raina et al. (2012) [11], Solanki et al. (2014) [12], and Chaudhari et al. (2019) [13], as well as with their recognized location along the orbital floor.

No statistically significant sex-based differences were observed in HCs morphometric parameters in the present study. This finding is consistent with Friedrich et al. (2017) [14], who reported no significant correlation between sex and HCs morphology or presence, and with Khojastepour et al. (2017) [15], who found no significant association between sex and the presence of HCs. Other sino-nasal imaging studies, including Shokri et al. (2019) [16], also found no significant sex-related differences in anatomical variations, including HCs. These findings suggest that sex does not appear to be a major determinant of HCs' occurrence or morphometric expression.

Also, no statistically significant association was found between HCs and CB in the present study at the 5% significance level; however, the result approached significance at the 10% level (OR = 2.37, 95% CI: 0.86–6.57), suggesting a possible trend toward co-existence. The literature specifically examining the association between these two variants is limited; nonetheless, some imaging studies suggested that HCs and CB may coexist [5].

The absence of a significant association between HCs and sinusitis is consistent with previous reports. Kim et al. (2006) found no significant relation between sinusitis and anatomic variations on CT [17], and Roman et al. (2016) reported only a small difference in the frequency of HCs between inflammatory (sinusitis) and control groups (OR = 1.14) [18].

4.3. Study Limitations

The present study has several limitations. The control ("healthy") group was selected based on radiologically normal CT scans and might have included individuals with undiagnosed sino-nasal pathology, potentially attenuating the observed association between HCs and sinusitis, especially maxillary sinusitis. In addition, the exclusion of 11 Iraqi individuals (10 males and 1 female) with extensive rhinosinusitis, characterized by opacification of the PNS due to extension of inflammatory secretions into the nasal cavity, may have introduced selection bias. This exclusion could have underestimated the prevalence of sinusitis and obscured a true association between HCs and sinusitis. Further, the relatively small number of participants with HCs (n = 38), together with subgroup analyses stratified by sex and laterality, likely further reduced the statistical power of the study, thereby limiting its ability to detect statistically significant associations.

The study's retrospective design also limits causal inference and is susceptible to selection and information bias; as detailed earlier, the control group was obtained from radiological imaging and may have included individuals with clinical or subclinical sino-nasal disease not apparent on CT. In addition, reliance on retrospective records resulted in heterogeneous documentation; variability in imaging techniques, including differences in imaging resolution, slice thickness, or CT acquisition protocols, may have introduced measurement inconsistency. At the same time, manual morphometric assessment on CT reconstructions may have contributed to observer-related (rater-related) error despite the use of MPRs to improve anatomical identification.

The relatively low prevalence of certain sino-nasal variants, particularly HCs and, to a lesser extent, OCs, together with multiple statistical comparisons and subgroup analyses, may have increased the risk of type I statistical error. On another note, the absence of comprehensive clinical data, including socio-demographic characteristics, history of smoking status, allergy history, comorbidities, medical and surgical history, medication use, and sinusitis severity, limited adjustment for potential confounders and reduced the generalizability of the findings beyond the studied Iraqi population. Another important limitation is that the sectional area of HCs was derived from two-dimensional coronal CT measurements rather than a true three-dimensional (volumetric) assessment and, therefore, may not fully reflect the actual extent of pneumatization.

4.4. Recommendations

Future research can investigate the morphological subtyping of HCs and their associations with anatomical variations in the middle and superior meatuses and turbinates, given the potential clinical and surgical relevance of these relationships. Although the present study specifically examined the association between HCs and the pneumatized middle turbinate (CB), the borderline statistical significance and the relatively small sample size suggest that the study may have been underpowered. Larger and more representative studies with a priori sample size calculations are therefore warranted to clarify this relationship. Future investigations can also evaluate whether different HCs' morphological subtypes might, or might not, differentially contribute to the pathogenesis of sinusitis by comparing well-defined cohorts of Iraqis with and without CRS. In addition, prospective longitudinal studies, using serial (consecutive) CT imaging in conjunction with time-series analyses, can examine the temporal changes in HCs' pneumatization and determine whether these changes might precede, accompany, or result from the development of sinusitis.

Although the present study did not identify a conclusive statistically significant association, the observed prevalence of HCs (36.9%) remains noteworthy compared with regional and international reports. The lack of comparative data from other Middle Eastern and Western populations limits the interpretation of potential population-specific variations. Future multicenter studies including Iraqi and regional populations (e.g., Iran, Jordan, and Saudi Arabia) and Western nations are warranted to clarify the possible contributions of genetic or ethnic factors to HCs prevalence.

Future studies can address these limitations through multicenter and prospective study designs with larger and more representative samples, standardized imaging protocols, predefined morphometric methods, and a priori statistical power calculations. Inclusion of patients with clinically and endoscopically confirmed CRS, together with comprehensive clinical data collection, would improve control of confounders and strengthen causal inference. Further, research may also evaluate volumetric pneumatization indices for HCs and compare them with two-dimensional area-based measures in relation to sinusitis or other outcomes.

Assessment of intra- and inter-observer reliability by experienced head-and-neck radiologists or otolaryngologists, as well as stratified analyses according to laterality, sex, and age, would further enhance the anatomical and clinical relevance of future research. Correlation of radiological findings with endoscopic or intra-operative observations may also help validate the identification, morphometric assessment, and clinical significance of HCs, particularly in relation to crucial anatomical structures relevant to the ostiomeatal complex and the orbital floor; these include the maxillary antral infundibulum, uncinate process, infraorbital nerve, and CRS-related mucosal changes in the maxillary sinus. Finally, to address inter-study heterogeneity, future systematic reviews and meta-analyses of relevant studies on HCs are warranted, similar to those conducted for other sino-nasal variants of interest, including CB [19,20] and others [1,20,21].

5. Conclusions

Haller cells were the least common of the evaluated sino-nasal anatomical variants in the studied Iraqi cohort, with a prevalence of 36.9%. Although unilateral right-sided occurrence was most frequent, their morphometric characteristics were generally symmetrical, with no significant side- or sex-based differences. The observed positive correlations among morphometric parameters, especially between length and sectional area, indicate that the size of HCs is more related to their pneumatization along the infraorbital border. Further, HCs showed no significant association with sex, NSD, OCs, or maxillary sinusitis, suggesting that they largely occur as an isolated anatomical entity in the Iraqi population. While

the borderline association with CB may indicate a possible tendency toward co-occurrence, this finding remains inconclusive.

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Abbreviations

The following abbreviations are used in this manuscript:

2D	Two-dimensional
3D	Three-dimensional
β	Beta/type II error probability
CB	Concha bullosa
CBCT	Cone-beam computed tomography
CI	Confidence interval
CRS	Chronic rhinosinusitis
CT	Computed tomography
df	Degrees of freedom
DICOM	Digital Imaging and Communications in Medicine
HCs	Haller cells
IQR	Interquartile range
MPRs	Multiplanar reconstructions
n	Sample size
NSD	Nasal septum deviation
OCs	Onodi cells
OMU	Ostiomeatal unit
OR	Odds ratio
p-value	Probability value
PNS	Paranasal sinuses
ρ	Spearman's rho correlation coefficient
SD	Standard deviation
SPSS	Statistical Package for the Social Sciences

VR	Volume rendering
χ^2	Chi-square statistic

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