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Original article

Anatomical Variations of Sphenoid Sinus Pneumatization in Libyan Adults Using Computed Tomography (CT) Scan

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Abstract

Background and aims. *With the help of endoscopic endonasal transsphenoidal approaches, lesions at the base of the skull can easily be accessed. The air in the nasal cavity and sphenoid sinus provides a physiological pathway for these procedures. Many factors determine the safety and course of action of the process. These include the anatomy of the patient's sphenoid sinus and skull base. Knowledge of the different anatomical variants of this sinus may help predict and prevent complications as the extent and pattern of sinus pneumatization vary from person to person. The main aim of this study is to initially determine the anatomical variations of the sphenoid sinus pneumatization in the Libyan population.* ***Methods***. *This retrospective study included computed tomography scans from 141 subjects attending healthcare centers in Benghazi, Libya, from May 2021 to March 2022. Their ages ranged from 18-80 years old, with a male-to-female ratio of (1.17:1). They were assessed for their type of sphenoid sinus based on the Güldner classification. The variability in the nature of the intersphenoid septum was also determined.* ***Results***. *The most common types of sphenoid pneumatization were the sellar (54.6%) and postsellar (31.2%). Extensions of pneumatization were seen in the greater wing of sphenoid, pterygoid process, and anterior clinoid process in 39%, 33.3%, and 18.4% of patients, respectively. The intersphenoid septum was most frequently shown to be single, specifically in the midline with lateral deviation.* ***Conclusions***. *The pneumatization of the SS is variable among the Libyan population. The clinical and surgical significance of the anatomical variants has been discussed, highlighting the need for a thorough preoperative evaluation of the sinus.*

Keywords: *Anatomical Variations, Sphenoid Sinus, Pneumatization, Intersphenoid Septum.*

Introduction

The transsphenoidal approaches have been the gold standard for sellar tumour resection for decades [1]. Yielding an optimal and wide operative field of view, they provide auspicious visualization of anatomical structures while being safe and minimally invasive.[2] The endoscopic endonasal transsphenoidal approach has lower morbidity and mortality rates than traditional open techniques.[3] It also can expand to all areas bordering the sphenoid sinus.[4] In these procedures, the skull base is accessed through the sphenoidal air sinus, marking an area of communication between intracranial and extracranial compartments.[5] Located deep within the skull in the middle cranial fossa, the sphenoid sinus (SS) is the least accessible paranasal sinus.[6] It communicates with the roof of the nasal cavity via the spheno-ethmoidal recess in its anterior wall.[7] Its boundaries are the frontal and ethmoidal bones anteriorly, the temporal bones laterally, and the occipital bone posteriorly. The SS is located in the body of the sphenoid bone, which is composed of the body, the lesser and greater wings, and the pterygoid process.[6] A midline inter-sphenoid septum (ISS), which may be absent, incomplete, or multiple, parts the sinus yielding two hemi-sinuses. The ISS is often laterally deviated and found anteroinferior to the sella.[7]
The variability in the anatomy of the SS is well established. [8-10] Pneumatization (the development of air cells), one of the clinically relevant variables, ranges from negligible to extensive.[11] Signs of SS pneumatization appear as early as six months of age, beginning at the ostia and progressing inferiorly, posteriorly, and laterally.[12] Pneumatization continues to extend until it reaches the back of the sella turcica. Reaching its mature size by the age of 12 to 15 years, it evolves slowly compared to other paranasal sinuses.[13] Hammer and Radberg [14] classified SS pneumatization into three based on its extension around the sella turcica; conchal, presellar, and sellar. This classification became fundamental to

transsphenoidal surgery's focus on the sellar region for more than 30 years.[15] Güldner [16] has added the postsellar variant by further evaluating the posterior extent of the sinus.

Pneumatization of the SS can extend from the body and into the clinoid processes, greater and lesser wings, pterygoid plates, processes, vomer, palatine, ethmoid and occipital bones, and the clivus.[17] These lateral extensions of SS pneumatization simplify access to the cavernous sinus, middle cranial fossa and petrous apex.[18] The ridges and depressions of these extensions closely relate the SS to indispensable vital structures. These include the optic nerve, cavernous sinus, internal carotid artery, frontal lobe, ventral surface of the brainstem, cranial nerves III-VI, and pituitary gland. [18, 19] According to the extent of SS pneumatization, the overlying bone can be thin or even absent, making these structures susceptible to iatrogenic injury.[20] The SS is often neglected due to its profound location. The inadequacy of surgeons to understand the variations of the structural landmarks of the SS is often described as a potential risk factor in clinical interventions.[21]

Being the best and most precise imaging method to demonstrate paranasal sinuses,[22] computed tomography (CT) has the advantages of showing bony details (via wide window settings) and good soft tissue outlines (via narrow window settings).[23] Magnetic resonance imaging (MRI) displays features about the location of the lesion and the adjacent structures rather than the bony structure itself. Both CT and MRI are used for optimal surgical guidance.[24]

A meticulous understanding of the anatomical variations of the SS helps understand pathological processes, allowing for optimal intraoperative guidance.[25] Pneumatization is critical in determining a patient's suitability for trans-sphenoidal approaches. It helps predict and avoid operative and post-operative complications.[3]

This study aimed to use CT scans to observe and interpret variations in SS pneumatization in Libyan adults and to highlight their clinical and surgical importance.

Methods

This retrospective study was conducted on Libyan adults who underwent paranasal or brain CT scans in healthcare centers in Benghazi, Libya, from May 2021 to March 2022. Individuals younger than 18 years old were excluded because, according to Gray's Anatomy,[6] the full extension of the SS does not take place until adolescence. Patients with fractures, apparent pathologies, and abnormalities in the anatomical area to be studied were also excluded. Imaging analysis and exclusion of indeterminate cases resulted from assessments of a radiologist and a neurosurgery consultant. The SS was assessed for the pattern of pneumatization and its extensions to the greater wing of sphenoid (GWS), pterygoid process (PP), and anterior clinoid process (ACP), as well as the variations in the ISS. The software RadiAnt DICOM Viewer 2021 was used to visualize the medical images of CT scans in sagittal, coronal, and axial planes. Statistical analysis of all the datasets was performed with SPSS, Version 26 (IBM, Armonk, New York).

Sinus Classification

Hammer and Radberg [14] classified the SS pneumatization into conchal, presellar, and sellar types. The Güldner [16] classification includes a fourth variant, the postsellar type. These classifications are based on evaluating the posterior extent of SS pneumatization with respect to the sella turcica (Table 1.0, 2.0). The conchal type is observed when the area below the sella turcica is entirely ossified and exists as a solid bone with no air sinus. In the presellar type, the air sinus does not exceed an imaginary vertical line parallel to the anterior wall of the sella. The SS of the sellar type is well-developed as it extends beyond the tuberculum sellae beneath; it may or may not show bulging of the sellar floor into the SS cavity. As for the postsellar variant, the air cavity reaches the body of the sphenoid bone and is beyond the imaginary line parallel to the posterior sellar wall (Figure 1.0).

Table 1. Prevalence of SS Pneumatization Types by Hammer and Radberg Classification

Hammer and Radberg Classification			
Paper	**Conchal (%)**	**Presellar (%)**	**Sellar (%)**
Current, 2022	1	13	86
Hamberger et al, 196125	3	11	86
Renn et al, 197526	0	20	80

Ouaknine and Hardy, 198727	3	12	85
Sethi and Pillay, 199528	0	27	73
Wang et al, 201018	0	2	98
Locatelli 201729	1	5	94
Raseman et al, 202030	0	6	94

Table 2. Prevalence of SS Pneumatization Types by Güldner Classification

Güldner Classification				
Paper	**Conchal (%)**	**Presellar (%)**	**Sellar (%)**	**Postsellar (%)**
Current, 2022	1	13	55	31
Liao et al, 200131	4	36	14	46
Li et al, 201032	2	31	21	47
Güldner et al, 201215	<1	7	57	36
Rahmati et al, 201633	0	2	15	84
Famurewa et al, 201834	2	1	57	40
Movahhedian et al, 2021 35	1	<12	36	52
Parameshwar et al, 202236	2	10	33	<56

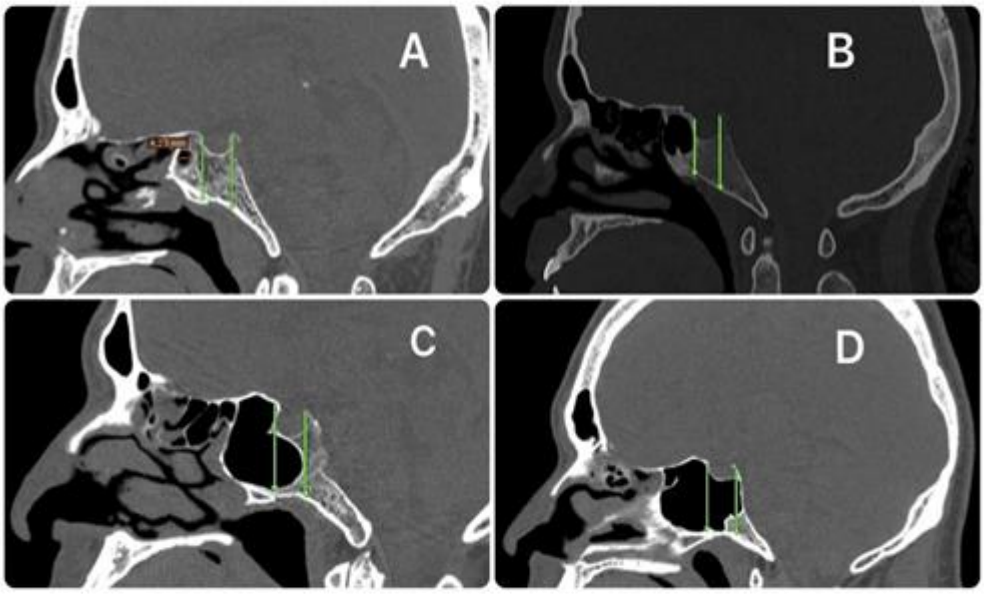

***Figure 1.0 – Classification of the posterior extent of sellar pneumatization**; Midsagittal CT images revealing types of sphenoid pneumatization. A: Conchal type. B: Presellar type. C: Sellar. D: Postsellar.*

Presence of ISS
In the criteria applied in this research, the ISS was classified as single (right side, midline, left side), incomplete, multiple, and absent. It is described as ISS since it is typically single.[6] A complete septum is defined as one that begins on the anterior wall of SS and ends on its posterior wall when viewed in the axial CT plane or from the superior to inferior borders of SS when seen in the coronal CT plane. The septum is considered incomplete if it does not fully extend as stated previously. If more than one septum is observed, the sphenoid sinus has multiple septa, and the ISS is thus labelled multiple. Occasionally, there may be no septum; therefore, it is considered absent.

Results
A total of 146 patients participated in this study. However, 141 individuals fulfilled the study entry criteria, of which 53.9% (n=76) were males and 46.1% (n=65) were females, with a male-to-female ratio of 1.17:1 (Figure 2.0). Ages ranged from 18-80 years old. Five cases were excluded from this study, including an individual with SS agenesis (Figure 3.0). There were also four patients with sinus mucocele represented on the CT scans as complete opacification of the sinus.

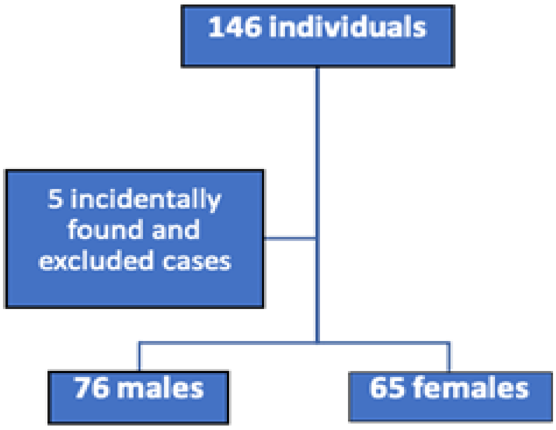

Figure 1.0 – Study Design.

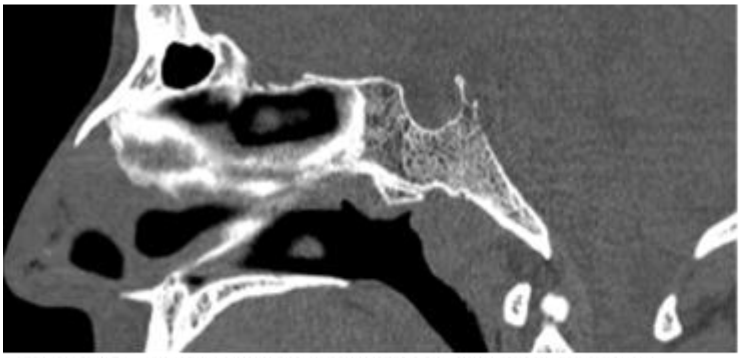

Figure 3.0 – Sagittal CT revealing sphenoid sinus agenesis (extremely rare).

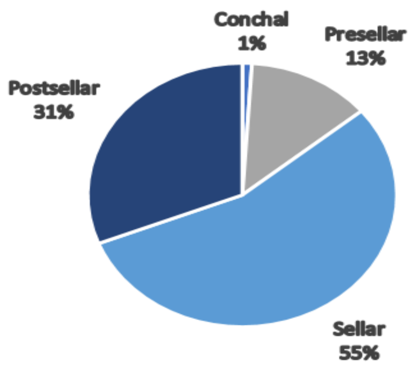

Figure 4.0 – Prevalence of Types of SS Pneumatization.

Pneumatization of GWS

Pneumatization of GWS was pneumatized in 55 patients (39.0%), of whom 20 (14.2%) had bilateral involvement, 16 (11.3%) the right side, and 19 (13.5%) the left (Figure 5.0, 6.0).

Pneumatization of PP

A total of 47 cases (33.3%) had pneumatization of the PP, of which 23 (16.3%) were bilateral, 9 (6.4%) were on the right side, and 15 (10.6%) were on the left side (Figure 5.0, 6.0).

Pneumatization of ACP

The ACP was pneumatized in 26 (18.4%) individuals, of whom 6 (4.3%), 9 (6.4%), and 11 (7.8%) were bilateral, right side, and left side, respectively (Figure 5.0, 6.0).

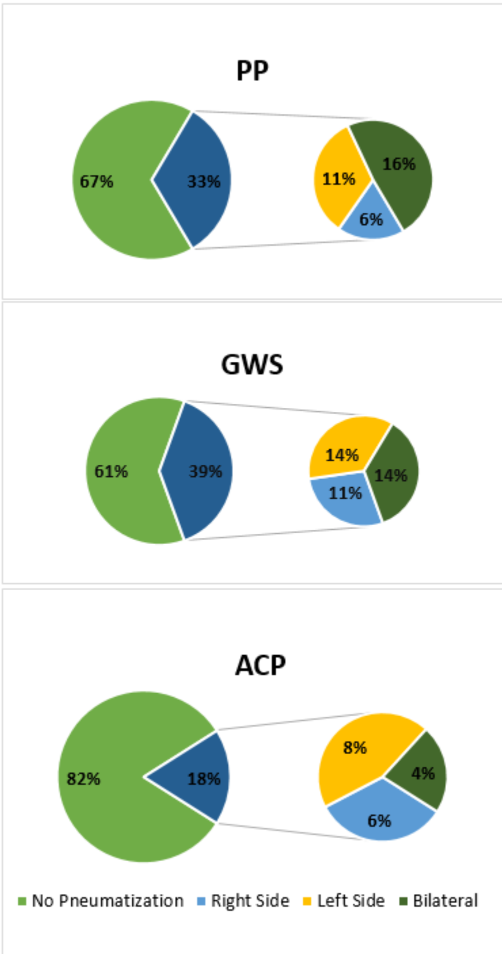

Figure 5.0 – Pneumatization of GWS, PP, and ACP.

ISS Variants

In this series, 83 (58.9%) had a single complete septum, the most common variant. This is followed by the presence of multiple septa, accounting for 41 (29.1%) patients. The incomplete and absent variants were found in 12 (8.5%) and 5 (3.5%) cases, respectively (Figure 6.0, 7.0, 8.0).

Figure 6.0 – Coronal CT image showing pneumatization of ACP (asterisks), GWS (circles), and PP (arrows). A septum parts the sinus to two hemisinuses.

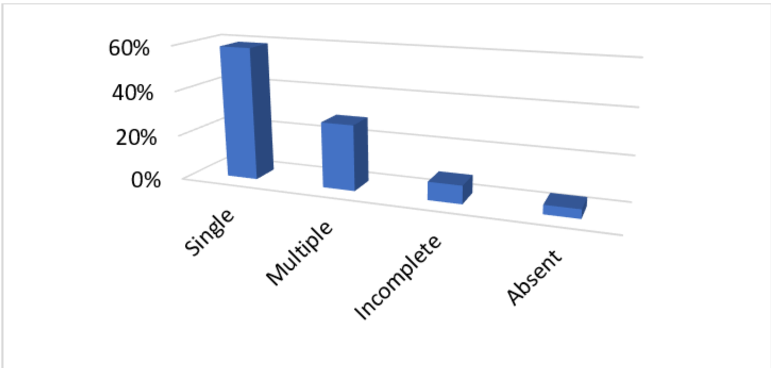

Figure 7.0 – Findings in Variations of Intersphenoid Septum.

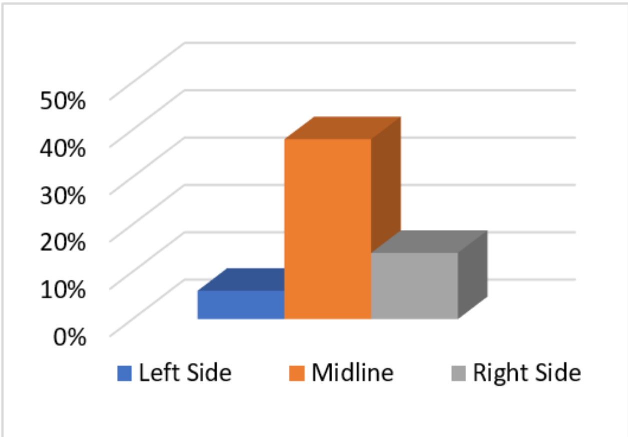

Figure 8.0 – Findings in Variations of Single ISS.

The individuals with conchal and presellar types of SS in this study had negligible extensions of pneumatization to the three structures assessed, with only two subjects with presellar SS having extensions to the left PP. On the other hand, the vast majority of individuals with PP pneumatization had either the sellar or postsellar variants. All patients with lateral extensions to GWS and ACP had either sellar or postsellar sinuses. Pneumatization to the ACP was the least overall compared to GWS and PP (Table 3.0).

Table 3. Type of SS Pneumatization and Extensions to GWS, PP, ACP

Type of SS Pneumatization	GWS				PP				ACP				Total
	Absent	Right	Left	Bilateral	Absent	Right	Left	Bilateral	Absent	Right	Left	Bilateral	
Conchal	2	0	0	0	2	0	0	0	2	0	0	0	2 1.4%
Presellar	18	0	0	0	16	0	2	0	18	0	0	0	18 12.8%
Sellar	53	6	9	9	56	5	8	8	65	3	7	2	77 54.6%
Postsellar	13	10	10	11	20	4	5	15	30	6	4	4	44 31.2%
Total	86 61%	16 11.3%	19 13.5%	20 14.2%	94 66.7%	9 6.4%	15 10.6%	23 16.3%	115 81.6%	9 6.4%	11 7.8%	6 4.2%	141

Extensions of SS pneumatization were found in 102 patients, whether unilateral on either side or bilateral. The Pearson correlation coefficient for GWS and PP was 0.589; for GWS and ACP was 0.225; and for PP and ACP was 0.296, all showing weak positive correlations, with the GWS and PP correlation coefficient being the strongest. The 2-tailed significance values were all highly significant ($p<0.05$) (Table 4.0). There was no identifiable correlation between the age or gender and the SS type, the presence of SS pneumatization extensions, or variations in the ISS.

Table 4. Correlations between Pneumatization

Items	Analysis	GWS	PP	ACP
GWS	Pearson Correlation	1	0.589	0.225
	Sig. (2-tailed)		.000	.023
	N	102	102	102
PP	Pearson Correlation	0.589	1	0.296
	Sig. (2-tailed)	.000		.003
	N	102	102	102
ACP	Pearson Correlation	0.225	0.296	1
	Sig. (2-tailed)	.023	.003	
	N	102	102	102

Discussion

This study revealed that the sellar type of SS was the most prevalent. The SS pneumatization most frequently extended laterally along the GWS. The ISS was often single, with the majority in the midline with a slight lateral deviation.

The past studies on the frequency of different SS pneumatization types are summarized in Table 1.0 and 2.0, comparing results over decades based on the Radberg14 classification

and the more recent papers using the Güldner [16] classification. An accurate classification of the sphenoid sinus pneumatization can help yield a practical preoperative evaluation of the risk of harming the SS and its surrounding vital structures. This classification is used to determine which physiological passage is more convenient to employ to access the skull base via transsphenoidal methods.[37]
Consistent with the literature, this study showed that the conchal and presellar types were less common than the sellar and postsellar types. [25-30,33-36] However, studies conducted by Liao et al. [31] and Li et al. [32] showed that the presellar type was more common than the sellar type. The ethnic backgrounds of the studied populations could contribute to this difference. An investigation conducted by Tomovic et al. [38] consisted of a multiethnic community comprised of African Americans, Caucasians, Asians, and Hispanics. No apparent differences in terms of ethnicity were found. The conchal and presellar kinds, however, are more common in Chinese people, according to research by Lu et al. [37]. This research constituted a North African population. Thus, little ethnical and racial heterogenicity in the prevalence of SS types cannot be ruled out.
Parallel to this study, the sellar type was more common than the postsellar one in papers conducted by Güldner et al. [16], Raseman et al.[30], and Famurewa et al.[34]. On the other hand, many past findings featured the postsellar type as the most prevalent. [31-33,35,36] When combined, the sellar and the postsellar SS pneumatizations have a prevalence of 85.8% in this study. It is important to note that these two are the most eligible for the endoscopic endonasal transsphenoidal approaches. This is because, in these variants, the floor and anterior wall of the sella typically measure less than 1 mm thick, making it easier to reach the sellar floor.[18] The trans-sphenoidal approach has been considered to be contraindicated in the case of conchal type due to unfavourable anatomy, as it joins SS agenesis and retropharyngeal carotid arteries (kissing carotids). [33,39]

Pneumatization of the Greater Wing of Sphenoid
Pneumatization of GWS is not widely assessed in previous literature compared to other lateral extensions. The existence of GWS pneumatization is based on whether the extension exceeds a vertical line at the foramen rotundum, similar to the study conducted by Hewaidi and Omami[19]. Famurewa et al. [34], John Earwaker[40], and Hiremath et al.[41] found that the GWS was pneumatized in 20%, 35%, 10.7%, and 12.75%, respectively. In the present findings, the GWS was pneumatized in 39%, being the most common lateral extension. The GWS being pneumatized usually doesn't result in any severe complications. However, arachnoid granulations may be present along the inner edge of the GWS. Upon enlargement, these granulations can result in iatrogenic cerebrospinal fluid rhinorrhea.[37]

Pneumatization of Pterygoid Process
Access to the base of the central skull can be gained through medial areas of the posterior maxillary walls in endoscopic endonasal transsphenoidal approaches when pneumatization of the PP is present.[3] When extensions reach beyond a horizontal plane crossing the vidian canal, the PP is recognized as pneumatized. Hewaidi and Omami[19] identified PP pneumatization in 29% of cases, whereas Famurewa et al.[34] identified it in 45.1%. Parameshwar et al. [36] and Hiremath et al. [41] found PP pneumatization in 29.63% and 31% of individuals, respectively. This study found that the PP was pneumatized in 33.3% of patients.

Pneumatization of Anterior Clinoid Process
Several papers have studied the incidence of ACP pneumatization. It was the least to be pneumatized out of the lateral extensions assessed, found in 18.4% in this series and 11.6-17.0% in the literature. [8, 19, 30, 34, 41] Anterior clinoidectomy is now the preferred method to access the cavernous sinus. This is useful in removing giant pituitary adenomas and clinoidal meningiomas, as well as the exposure of para-clinoid and upper basilar artery lesions. When there is a pneumatized ACP, the incidence of rhinorrhea following anterior clinoidectomy has been reported to increase from 2.7 to 7.0%.[42]

Intersphenoid Septum Variants
The ISS is a significant anatomical landmark in the SS. It frequently varies in number and insertion as the osseous covering of the internal carotid artery is a common insertion in many individuals.[43] In research by Famurewa et al. [34], a single ISS was seen in 46.9% of their series, multiple septa in 50.6%, and 2.5% had no septum within the sinus. The findings of this paper show that 58.9% had a single septum, 29.1% had multiple septa, and 3.5% had

no septum. The septum must be removed to expose the sellar floor during endoscopic surgery and create sufficient surgical space. This means that removing the septum in patients with an ISS inserted into the bony covering of the internal carotid artery requires careful handling. In this case, an injury or fracture of the ISS could damage the vessel and result in an intraoperative emergency and significant postoperative complications.[43]
Moreover, this study showed that lateral extensions were much more frequent as the SS was posteriorly extended, as shown in Table 3.0. Conchal and presellar variants had fewer extensions to GWS, PP, and ACP than sellar and postsellar types. They may be related in terms of the size of the air cavity; a more prominent sinus would theoretically occupy more space, extending to more anatomical regions. Despite having a highly significant p-value, the correlation coefficients in Table 4.0 were all weak, showing a mild positive correlation. This has to do with the sample size. The lateral extensions were present in 102 individuals. This means the study had just enough statistical power to identify even fragile effects. Thus, the presence of a lateral extension of pneumatization in one of the anatomical landmarks is associated with pneumatization to another landmark; however, the effect is shown to be minor.

Limitations and Recommendations
Evidence of many conditions, such as prior sinus surgery, sino-nasal tumours, and nasal polyposis, would help yield more detailed exclusion criteria. We advise the performance of a study on the prevalence of pattern and extent of sphenoid sinus pneumatization in Libyan adults with endoscopic examinations and CT scans to compare the results of the two modalities. Nevertheless, the authors believe this study has provided additional information on the variations of the anatomy of the SS among the Libyan population.

Conclusions
Neurosurgeons and otolaryngologists favour endoscopic endonasal transsphenoidal approaches over more traditional operations for handling lesions of the skull base. Based on the findings of this research, it is reliable to conclude that the pneumatization of the SS is variable among the Libyan population. The sellar variant appears to be the most common type of SS, with pneumatization of the GWS as the most common lateral extension. The study also shows that the ISS demonstrates noticeable variations, with the single type being the most abundant. Thus, radiologists and surgeons must be aware of the different pneumatization patterns, their lateral extensions, and the nature of the ISS. The authors highly recommend a detailed pre-operative evaluation of this structure to yield safe and effective surgical outcomes.

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