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Morphology, pneumatization, septation, and protrusion of nearby structures into the sphenoid sinus: A retrospective radiological study

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Abstract. The morphology of the sphenoid sinus is critical in planning endoscopic sinus surgery, pituitary gland surgery, cerebrospinal fluid leak repair, the management of chronic sphenoid sinusitis, and the evaluation of skull base tumours. The objective of this study was to evaluate the morphology of the sphenoid sinus, with an emphasis on classification, septation, protrusion of structures, and dehiscence of the bony covering. In this retrospective radiological study, the morphology of the sphenoid sinus was analysed using 400 computed tomography scans. According to Hamberger's classification, the sphenoid sinus was classified into postsellar and presellar varieties. Additionally, the extent of pneumatization of the pterygoid process, anterior clinoid process, and greater wing of the sphenoid was noted. The anteroposterior, transverse, and vertical diameters of the sphenoid sinus were also measured. The relative positions of the genu of the internal carotid artery, vidian canal, and intracanalicular optic nerve were also recorded. The mean anteroposterior length, transverse length, and vertical length of the sphenoid sinus were found to be 29.3 (±2.8), 31.9 (±2.7), and 22.8 (±1.9) mm, respectively. The sellar type was found in 90% of subjects, while the remaining 10% had the presellar type. Only two subjects had the concha type of sinus. A single septum was noted in 32% of cases.

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Pneumatization of the pterygoid process was found in 22.5%, the anterior clinoid process in 27%, and the greater wing of the sphenoid in 21.25%. Optic nerve protrusion occurred in 24.5% of cases, and 23% of optic canals were dehiscent. The findings of this study hold significant relevance for neurosurgery, particularly in procedures involving the skull base, such as transsphenoidal surgery and optic nerve decompression

Keywords: paranasal air sinuses; anatomy; vidian canal; optic nerve; presellar; *sella turcica*

INTRODUCTION

The morphology of the sphenoid sinus has gained significance in recent years with the adoption of the endonasal endoscopic approach to the sphenoid sinus. The anatomy of the sphenoid sinus is crucial for surgeons operating at the base of the skull to address sinus inflammation, tumours, and pituitary gland surgery. Understanding the detailed morphology of the sphenoid sinus is essential to avoid complications and ensure safe navigation during these complex surgical procedures. Researchers K. Badran *et al*. [1] opined that pre-operative evaluation of the sphenoid sinus is essential for appropriate planning of approaches to skull base structures and for avoiding injury to nearby structures. The classification of the sphenoid sinus is typically based on its pneumatization pattern. According to Hamberger's classification, the sphenoid sinus is categorised into sellar, presellar, and postsellar types [2]. There are wide variations in the reported prevalence of these three varieties. S.B. Hiremath *et al.* [3] report 22.2% of presellar and 76.6% of sellar types among 500 patients. P. Thakur *et al*. [4] report 89.5% sellar variety. In addition, there are differences in the methodologies followed for the classification of the sphenoid sinus.

Pneumatization of the sphenoid sinus influences the position of structures related to the sinus, including the internal carotid artery, maxillary nerve, optic nerve, and vidian canal. O.C. Famurewa *et al.* [5] opine that a detailed evaluation of these structures is essential before the endonasal transsphenoidal approach to the skull base. According to N. Lakshman *et al.* [6], the extent of pneumatization in the sphenoid sinus and pterygoid process is closely associated with the type of vidian canal. P. Dahal *et al.* [7] have noted that pneumatization of the anterior clinoid process influences the type of optic nerve and reports a frequent association of type 3 optic nerve with a pneumatized anterior clinoid process. Y.J. Kang *et al*. [8] have reported that when sphenoid sinus pneumatization is inadequate, the intersphenoid septum is attached to the paraclival internal carotid artery or is found very close to the paraclival part. Additionally, S. Şimşek & A. İşlek [9] report age-related changes in sphenoid sinus pneumatization.

These findings suggest that the extent of sphenoid sinus pneumatization affects its relationship with nearby structures and that there are individual differences in this anatomy. Therefore, it is essential to assess the relationship between the optic nerve, vidian nerve, internal carotid artery, maxillary nerve, and sphenoid sinus in a specific population. Surgeons and radiologists must navigate this intricate landscape with precision, utilising advanced imaging techniques and classification systems to tailor interventions to individual anatomical variations. Consequently, this study was designed with the objectives of reporting the morphology of the sphenoid sinus, with an emphasis on classification, septation, protrusion of structures, and dehiscence of the bony covering.

MATERIALS AND METHODS

Study design: A total of 524 head computed tomography (CT) scans were analysed for sphenoid sinus morphology, and 400 scans were selected for measurements after excluding others according to the inclusion criteria. The study was conducted at AJ Institute of Medical Sciences and Research, Mangalore, from May 2022 to May 2024. Out of the 400 CT scans selected for the study, 256 cases were female and the rest were male. The mean age of the study group was 35.7 years, with ages ranging from 10 to 82 years. All patients were South Indians and Caucasians. Anatomical measurements and observations were performed on the coronal and axial sections of the CT scans.

Only scans with no radiologically detectable disease were included in the study. Patients with a history of sinus surgery, sinonasal tumours, nasal polyposis, severe cervical arthropathy, or head and neck injuries were excluded from the study. CT scans with 4-mm slices were reviewed, extending from the anterior frontal sinus to the anterior sphenoid sinus. Due to a lack of morphometric data in this area, the sections were spaced slightly further apart. For precise evaluation of adjacent structures and their relationship to the sphenoid sinus, contiguous transverse CT scans with a 2-mm slice thickness were analysed in an anteroposterior direction. Similarly, 2-mm coronal CT sections were examined for corresponding morphology and related structures. Each image was centred on the nasal cavity and supraorbital margin. Anatomical measurements and observations were conducted using both coronal and axial sections of the CT scans.

Pneumatization of the pterygoid process, anterior clinoid process, and greater wing of the sphenoid bone were observed in the selected CT scans. Sphenoid sinus classification based on Hamberger's classification was performed according to the type of pneumatization, which includes postsellar and presellar varieties. Bulging of the sella floor into the developed sinus is considered the sellar type. If the cancellous bone of the sphenoid extends from beneath the *sella turcica* to the anterior aspect of the floor, it is considered the presellar type. If the sphenoid sinus is absent and entirely filled with cancellous bone, it is classified as the concha type.

Septation of the sinuses was noted. In each CT scan, the dimensions of the sinuses, including the anteroposterior, transverse, and vertical diameters, were recorded. The anteroposterior diameter is measured from the anterior nasal spine to the posteriormost point on the wall of the sphenoid sinus in the axial plane. At the level of the pterygoid process in the coronal plane, the transverse diameter of the sphenoid sinus represents the distance between the lateral most points on the walls of the sphenoid sinus. The vertical length is measured from the highest point of the sinus roof (the floor of the *sella turcica*) directly down to the lowest point on the sinus floor in the coronal section.

Additionally, details regarding the protrusion of the internal carotid artery, optic nerve, maxillary nerve, and vidian nerve were documented. Structures were considered to have protruded into the sphenoid sinus if a vertical line drawn through each structure in the coronal section showed a clear delineation between the structure and the sinus, with the line falling within the boundaries of the sinus. Dehiscence of the walls of the internal carotid artery, intracanalicular optic canal, vidian canal, and maxillary nerve was noted. If there was no visible bony structure separating the sinus from the evaluated structure, it was considered dehiscent. If the bone was too thin and the presence or absence of dehiscence could not be ascertained by two evaluators on two different occasions, such cases were accepted as instances of dehiscence. The distance from the anterior nasal spine to the rostrum of the sphenoid was measured. The presence or absence of Onodi cells (posterior ethmoid cells lying within the sphenoid sinus) was noted.

Analysis of data: All continuous data are expressed as means with standard deviations. In this retrospective radiological study, the morphology of the sphenoid sinus was analysed. Any right-left differences were evaluated using the t-test and chi-square test. The study protocol was approved by the institutional ethics committee (AJEC/Rev/30/2022). The study was conducted in line with the International Declaration of Helsinki [10], and all participants consented to participation.

RESULTS

A total of 400 CT scans were evaluated for sphenoid sinus morphology and its relationship with important neighbouring structures.

Sphenoid sinus dimensions: The mean anteroposterior length of the sphenoid sinus was 29.3 (±2.8) mm, with a maximum measured length of 39.56 mm and a minimum length of 22.12 mm. The mean transverse length of the sphenoid sinus was 31.9 (±2.7) mm, with a maximum measured length of 37.6 mm and a minimum length of 24.3 mm. The mean vertical length of the sphenoid sinus was found to be 22.8 (±1.9) mm, with a maximum measured length of 27.7 mm and a minimum length of 19.68 mm.

Sphenoid sinus classification: The sphenoid sinus is classified based on pneumatization. The sellar type was found in 90% of subjects. Pneumatization that is limited to the area anterior to the *sella turcica* is considered the presellar type. The presellar type was found in 10% of patients. Those with minimal or absent pneumatization are considered the conchal type. The conchal type was noted in 2 subjects (both females). There was no statistically significant difference between the types of sphenoid sinuses among males and females (sellar type $p=0.58$ and presellar $p=0.3$).

Septation of the sphenoid sinus: Among the scans analysed, there was only one septum in 32%, two septa in 23% (Fig. 1), three septa in 20%, and four septa in 7%. The total number of sinuses varies depending on the total number of septa (including accessory septa), which can differ in the anterior and posterior parts of the sphenoidal sinus. A single septum may bifurcate into two at the lower part of the sinus, as observed in 9 subjects.

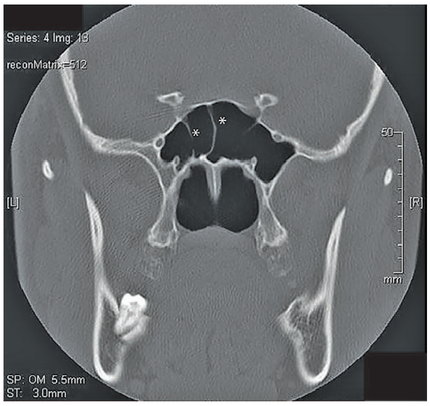

Figure 1. Coronal section of CT showing two septa in the sphenoid sinus

Notes: * indicates vertical sphenoid sinus septa

Source: image obtained from the Department of Radiology, evaluated by the authors of this study for paranasal sinus pathology, showing normal sphenoid sinus anatomy

Pneumatization details: 90 subjects (22.5%) had a pneumatized pterygoid process, of which 38 (9.5%) had bilateral pneumatization (Fig. 2), 32 (8%) patients showed left-sided pneumatization, and 20 (5%) patients exhibited right-sided pneumatization. The anterior clinoid process was pneumatized in 108 (27%) subjects. 42 (10.5%) subjects had bilateral pneumatization, 18 (4.5%) exhibited it only on the right side, and 25 (6.25%) on the left side. Pneumatization of the greater wing of the sphenoid bone was observed in 85 patients (21.25%). Among these, 38 patients (9.5%) exhibited bilateral pneumatization, 20 patients (5%) had pneumatization on the right side, and 32 patients (8%) had pneumatization on the left side. Statistically significant differences were found, with a higher prevalence of pneumatization on the left side for the anterior clinoid process, greater wing of the sphenoid, and pterygoid process compared to the right side.

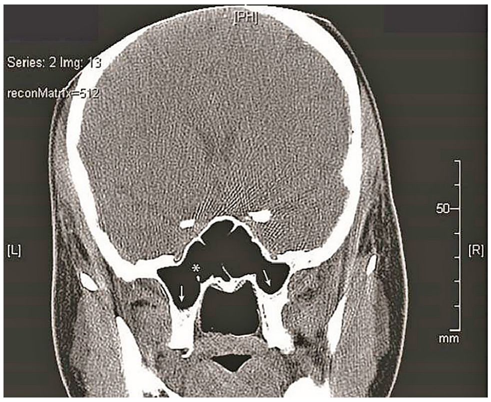

Figure 2. The coronal section of CT shows bilateral pneumatization of the pterygoid process and greater wing of the sphenoid with vidian canal protrusion

Notes: the white arrow indicates the pneumatized pterygoid process; * indicates the protruded vidian canal into the sphenoid sinus; R – right side; L – left side

Source: image obtained from the Department of Radiology, evaluated by the authors of this study for paranasal sinus pathology, showing normal sphenoid sinus anatomy

The protrusion and dehiscence observed are tabulated in Table 1. The optic nerve and vidian canal exhibited the greatest protrusion. The walls of the optic canal and vidian canal (Fig. 3) showed the highest dehiscence. The prevalence of optic nerve protrusion, optic nerve dehiscence, internal carotid artery dehiscence, maxillary nerve dehiscence, maxillary nerve protrusion, vidian canal protrusion, and vidian canal dehiscence were statistically different between the right and left sides.

Table 1. Protrusion and dehiscence observed during CT scan evaluation (n = 400)

	ON protrusion	ON dehiscence	ICA protrusion	ICA dehiscence	MN protrusion	MN dehiscence	VC protrusion	VC dehiscence
Bilateral	98 (24.5%)	92 (23%)	94 (23.5%)	37 (9.25%)	88 (22%)	39 (9.75%)	96 (24%)	42 (10.5%)
Left	36 (9%)	43 (10.75%)	42 (10.5%)	18 (4.5%)	26 (6.5%)	15 (3.75%)	30 (8%)	46 (11.5%)
Right	16 (4%)	56 (14%)	36(9%)	56 (14%)	34 (8.5%)	10 (2.5%)	52 (13%)	55 13.75%)
Total	150 (37.5%)	191(47.75%)	172 (43%)	111 (27.75%)	148 (37%)	64 (16%)	178 (44.5%)	143 (35.75%)

Notes: ON – optic nerve; ICA – internal carotid artery; MN – maxillary nerve; VC – vidian canal
Source: compiled by the authors

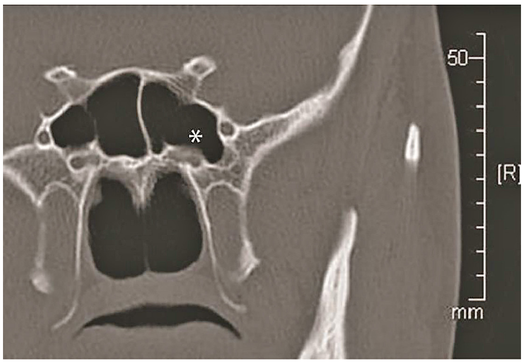

Figure 3. The coronal section of CT shows a dehiscent vidian canal on the right side
Notes: * indicates dehiscent vidian canal; R – right side
Source: mage obtained from the Department of Radiology, evaluated by the authors of this study for paranasal sinus pathology, showing normal sphenoid sinus anatomy

The mean distance from the anterior nasal spine to the rostrum of the sphenoid was 8.2 cm (range 7.6 to 1.5 cm). The mean inter-carotid artery distance was 14 mm (range 9 to 18 mm). A total of 53 cases showed Onodi cells, accounting for 13.25%. Onodi cells were bilateral in 24 cases. They were found on the right in 9 cases and on the left in 20 cases.

DISCUSSION

The classification of the sphenoid sinus into sellar, presellar, and conchal types is important in various clinical scenarios, particularly those involving endoscopic sinus surgery. The sellar type is the most advantageous for endoscopic sinus surgery because it provides optimal access to the sphenoid sinus and reduces the likelihood of complications. Due to its small size and limited access to the sphenoid sinus, the conchal type poses challenges for endoscopic sinus surgery [11]. In addition, the sellar type is the ideal variant for transsphenoidal surgery, as it provides direct access to the *sella turcica* without requiring extensive drilling. The presellar type requires more drilling to reach the *sella turcica*. According to O.C. Famurewa *et al.* [5] and G. Zada *et al.* [12], the conchal type is not suitable for transsphenoidal surgery due to the lack of access to the *sella turcica*. The reported prevalence of the sellar type varies widely. For instance, S.B. Hiremath *et al.* [3] report 76.6% as the complete sellar variety, while P. Thakur *et al.* [4] report 89.5% as the sellar variety. The authors of this study identified the sellar variety in 90% of subjects. The presellar type varies from 17% to 21%, and the conchal type varies from 2% to 28%. S. Sagar *et al.* [13] report the presellar variety in 26.3% of subjects, while S.B. Hiremath *et al.* [3] report the presellar variety in 22.2% of subjects. The authors of this study identified the presellar variety in 10% of subjects.

The pneumatization of the pterygoid process refers to the extension of pneumatic spaces into the pterygoid process of the sphenoid bone. The clinical significance of pterygoid process pneumatization is often related to its impact on adjacent structures and surgical considerations. Pneumatization can influence the anatomy of the skull base and may be relevant in procedures involving the sphenoid sinus or neighbouring structures. Additionally, variations in pneumatization are important for radiologists and surgeons to consider when interpreting imaging studies and planning interventions in the craniofacial region. In the present study, 27% of subjects were found to have pneumatized pterygoid processes. M.H. Alam-Eldeen *et al.* [14] report pneumatization in 61.6% of subjects. However, the study by A. Rahmati *et al.* [15] has shown a much lower rate of 38.9% pneumatization of the pterygoid process. Differences in populations considered, along with variations in the methodology of assessment, account for the wide range of prevalence reported in previous studies. Pneumatization increases with age, reaching its peak in adulthood. Though pneumatization is reported to commonly involve the medial pterygoid plate, this study did not attempt to report such differences in pterygoid plate pneumatization. Overall, the prevalence of pterygoid process pneumatization is generally considered common, and it is an aspect of normal anatomical variation. A well-pneumatized pterygoid process is considered an important anatomical corridor for accessing middle cranial fossa structures related to the cavernous sinus. For example, extended transnasal endoscopic techniques can access the pterygoid process via the medial aspect of the posterior maxillary wall. This study found a notable association between the presence of ipsilateral pneumatization of the pterygoid process and protrusion of the vidian canal.

Anterior clinoid process pneumatization occurs when air cells from the sphenoid and ethmoid sinuses extend into the anterior clinoid process. C.C. Shen *et al.* [16] reported that pneumatization can weaken the bone and increase the risk of cerebrospinal fluid (CSF) leaks during procedures such as optic nerve decompression and transsphenoidal surgery. Similarly, pneumatization can alter the anatomical relationships of important structures, such as the genu of the internal carotid artery and the intracanalicular part of the optic nerve, thereby increasing the risk of injury during surgery. Understanding the extent of anterior clinoid process pneumatization is crucial for planning and performing skull base surgeries safely. During optic nerve decompression, anterior clinoid process pneumatization can create a natural tunnel for the optic nerve, facilitating decompression surgery. However, A. Andrianakis *et al.* [17] report that such decompression also increases the risk of CSF leaks and requires careful drilling. In this study, 27% of the subjects examined had a pneumatized anterior clinoid process.

Protrusions and dehiscences in the walls of the sphenoid sinus are anatomical variations that can have significant clinical implications in various aspects of otolaryngology and neurosurgery. These altered relationships can increase the risk of injury to structures during surgery, particularly during endoscopic sinus surgery and transsphenoidal surgery. Protrusions can trap mucus and debris within the sinus, making it more susceptible to inflammation and infection, as noted by G. Hewaidi *et al.* [18]. Dehiscence can expose the underlying nerves to irritants from the sinus cavity, potentially contributing to trigeminal neuralgia. The prevalence of protrusions and dehiscences varies depending on the population studied and the imaging technique used. In the present study, it was observed that the maximum protrusion and dehiscence originated from the optic nerve among the structures related to the walls of the sphenoid sinus.

Septation of the sphenoid sinus can potentially hinder access to the *sella turcica*, making it more challenging to perform transsphenoidal surgery. This study observed various types of septation, and the details of individual septa aid in customising the transsphenoidal approach. A. Vaezi *et al.* [19] define the Onodi cell as an anatomical variant where the posterior ethmoid sinus pneumatizes into the sphenoid bone. Additionally, the presence of multiple septa or chambers within the sinus can complicate its morphology, necessitating detailed preoperative assessments for safe surgical interventions. In an Indian study, R.M. Itagi *et al.* [20] reported that 33.3% of subjects had Onodi cells. However, this study found a much lower prevalence of Onodi cells.

The classification and pneumatization patterns of the sphenoid sinus, pterygoid process, and anterior clinoid process are crucial for both clinical and surgical planning, particularly in endoscopic sinus surgery and transsphenoidal procedures. Understanding the variations in sphenoid sinus types – sellar, presellar, and conchal – is essential for optimising surgical access and minimising risks, with the sellar type being the most favourable for both sinus and skull base surgeries. While common anatomical variations, the pneumatization of the pterygoid process and the anterior clinoid process can significantly alter the relationship of critical neurovascular structures, increasing the risk of complications such as CSF leaks and nerve injuries. Careful preoperative assessment, including detailed imaging studies, is imperative for safe and effective surgical interventions. Additionally, septations, dehiscences, and protrusions in the walls of the sphenoid sinus, as well as the presence of Onodi cells, further complicate surgical approaches and highlight the importance of individualised planning to prevent complications and ensure successful outcomes. Understanding these variations provides a foundation for safer and more precise skull base surgeries.

CONCLUSIONS

In line with the objectives of the study, the morphology of the sphenoid sinus has been reported with an emphasis on classification, septation, protrusion of structures, and dehiscence of the bony covering. The mean anteroposterior length, transverse length, and vertical length of the sphenoid sinus were found to be 29.3 (±2.8), 31.9 (±2.7), and 22.8 (±1.9) mm, respectively. The sellar type was observed in 90% of subjects, while the presellar type was found in 10% of patients, and the conchal type was noted in 2% of subjects. Pneumatization of the pterygoid process was identified in 22.5%, the anterior clinoid process was noted in 27%, and the greater wing of the sphenoid was noted in 21.25%. Protrusion of the optic nerve was found in 24.5%, and 23% of optic canals were dehiscent. Protrusions and dehiscences in key structures, such as the optic nerve and vidian canal, were observed in a substantial number of subjects, with 47.75% showing optic nerve dehiscence and 44.5% exhibiting vidian canal protrusion. The study also revealed that the septation of the sphenoid sinus varied, with 32% of cases showing one septum, 23% with two septa, and fewer subjects presenting with three or four septa, which could complicate surgical access.

The findings of this study hold significant relevance for neurosurgery, particularly in procedures involving the skull base, such as transsphenoidal surgery and optic nerve decompression. The presence of anatomical variations, such as pneumatization of the pterygoid and anterior clinoid processes, along with septations and dehiscences, presents potential challenges. These variations can alter the proximity and vulnerability of critical neurovascular structures, including the optic nerve, internal carotid artery, and vidian canal, increasing the likelihood of complications, such as cerebrospinal fluid leaks, nerve injuries, and vascular damage during surgery. Future research could explore the impact of these anatomical variations on long-term surgical outcomes, particularly in high-risk patients. Additionally, studies involving larger, more diverse populations may provide deeper insights into the prevalence and clinical significance of these variations across different demographics.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Морфологія, пневматизація, септація, виступ сусідніх структур у клиноподібну пазуху – ретроспективне радіологічне дослідження

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Анотація. Морфологія сфеноїдного синуса є критично важливою для планування ендоскопічної синусної хірургії, хірургії гіпофіза, ремонту витоків ліквору, лікування хронічного сфеноїдного синуситу та під час оцінки пухлин основи черепа. Метою цього дослідження було оцінити морфологію сфеноїдного синуса з акцентом на класифікацію, перегородки, випинання структур та деісценцію кісткового покриття. У ретроспективному радіологічному дослідженні було проаналізовано морфологію сфеноїдного синуса, використовуючи 400 комп'ютеризованих томографій. Згідно з класифікацією Гамбергера, сфеноїдний синус було класифіковано на постселерний і преселерний варіанти. Крім того, було зафіксовано ступінь пневматизації крилоподібного відростка, переднього клиноподібного відростка та більшого крила сфеноїдної кістки. Відзначалися антеропостеріорні, поперечні та вертикальні діаметри сфеноїдного синуса. Відносне положення гену внутрішньої сонної артерії, видіан каналу та інтраканалярного зорового нерва також було зафіксовано. Середня антеропостеріорна довжина, поперечна довжина та вертикальна довжина сфеноїдного синуса склали 29,3 (±2,8), 31,9 (±2,7) та 22,8 (±1,9) мм відповідно. Тип селеру був виявлений у 90 % суб'єктів, а решта 10 % мали тип преселери. Лише у двох суб'єктів був виявлений тип конхи. Одна перегородка була зафіксована у 32 %. Пневматизація крилоподібного відростка спостерігалася у 22,5 %, переднього клиноподібного відростка – у 27 %, а більшого крила сфеноїдної кістки – у 21,25 %. Випинання зорового нерва спостерігалося у 24,5 %, а 23 % зорових каналів мали деісценцію. Результати цього дослідження мають значну важливість для нейрохірургії, зокрема, для процедур, що стосуються основи черепа, таких як транссфеноїдальна хірургія та декомпресія зорового нерва

Ключові слова: параназальні повітряні синуси; анатомія; видіан канал; зоровий нерв; преселер; *sella turcica*