Original Article

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Anatomical Variations of the Sphenoid Sinus in Acromegalic versus Non-Acromegalic Patients with Pituitary Adenoma: Implications for Surgical Planning

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Abstract:

Objective: To compare the anatomical differences of the sphenoid sinus and adjacent critical structures between patients with hormone-producing pituitary tumors, distinguishing between acromegalic and non-acromegalic groups, to optimize surgical planning and anticipate potential complications.

Material and Methods: A retrospective analysis was conducted on 150 patients diagnosed with hormone-secreting pituitary adenomas (50 acromegalic and 100 non-acromegalic) treated at the Neurosurgery Outpatient Clinic, Songklanagarind Hospital, between January 1, 2012 and December 31, 2022. Patient demographics and sphenoid sinus anatomical characteristics were assessed using computed tomography (CT) scans in collaboration with radiologists. Statistical analysis was performed using the R program with a significance threshold of p-value<0.05.

Results: Acromegalic patients exhibited significantly higher rates of post-sellar sphenoid pneumatization (p-value=0.002), sphenoid septum attachment to the optic nerve (p-value=0.018), and Onodi cells (p-value=0.011). The distance between the sphenoid rostrum and Vidian canal was significantly greater in acromegalic patients (p-value<0.001 right side, p-value=0.008 left side). Additionally, acromegalic patients had higher incidences of Vidian nerve protrusion (p-value=0.013), optic nerve protrusion (p-value<0.001), optic nerve dehiscence (p-value=0.025), and internal carotid artery (ICA) dehiscence (p-value=0.034). The intercarotid distance was significantly narrower in acromegalic patients (mean 16.4 mm, p-value<0.001).

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Conclusion: Patients with acromegaly and hormone-secreting pituitary adenomas demonstrate distinct anatomical variations in the sphenoid sinus and adjacent structures compared to non-acromegalic patients. These differences underscore the necessity for thorough preoperative evaluation and meticulous surgical planning to minimize risks during transsphenoidal pituitary surgery.

Keywords: acromegaly, anatomic variations, Pituitary adenoma, Rhinology, skull base surgery, Sphenoid Sinus, transsphenoidal surgery

Introduction

Pituitary adenomas are among the most common intracranial tumors, and transsphenoidal surgery, particularly the endoscopic endonasal approach (EEA), is considered the gold standard for their removal[1,2]. This approach relies heavily on the sphenoid sinus as a surgical corridor, making its anatomical characteristics crucial for operative planning and surgical safety. However, the sphenoid sinus exhibits considerable anatomical variability, which can significantly affect surgical accessibility and increase the risk of intraoperative complications[3,4].

The sphenoid sinus exhibits wide anatomical variability in terms of size, pneumatization pattern, and extension into adjacent bony structures, which has important clinical and surgical implications. Several studies have reported that sphenoid pneumatization can extend into structures such as the pterygoid processes, dorsum sellae, and clinoid processes, with varying prevalence across populations. For example, a recent CT-based study in a Northern Italian cohort demonstrated that over 57% of patients exhibited some form of anatomical variant, with the most common being pneumatized pterygoid processes (39.6%), dorsum sellae (32.9%), and clinoid processes (20.3%), often occurring in combination without significant sex differences[4]. These findings highlight the inherent interindividual diversity of sphenoid sinus anatomy, reinforcing the importance of population-specific data to guide safe and effective transsphenoidal surgical planning.

Acromegaly, a chronic endocrine disorder caused by growth hormone (GH)-secreting pituitary neuroendocrine tumors, leads to characteristic changes in both skeletal and soft tissue structures. Patients with acromegaly often show distinct morphological differences in the skull base, nasal cavities, and paranasal sinuses—particularly within the sphenoidal region[5]. These anatomical alterations may result in a deeper and narrower surgical field and more frequent carotid artery prominence[6], thereby posing additional challenges and increasing the risk of complications during EEA.

Given these considerations, this study aimed to evaluate and compare the sphenoid sinus anatomy between patients with acromegaly and those without. The findings are expected to enhance preoperative assessment and inform surgical strategy adjustments to optimize outcomes and reduce complications in transsphenoidal surgery.

Material and Methods

Data were retrospectively collected from 150 patients diagnosed with hormone-secreting pituitary adenomas who were treated at the Neurosurgery Outpatient Clinic, Songklanagarind Hospital, between January 1, 2012 and December 31, 2022. The study cohort included 50 patients with acromegaly and 100 without. Patients with a history of skull base surgery, facial trauma, or incomplete imaging data were excluded. All patients underwent high-resolution computed tomography (CT) of the paranasal sinuses. Scans were acquired using a 64-slice multidetector CT scanner, with axial images reconstructed into coronal and sagittal planes at 1-mm slice intervals using bone algorithm settings. Anatomical evaluations were performed using the hospital's picture archiving and communication system (PACS; Synapse®, FUJIFILM) with multiplanar navigation tools.

CT image assessments were conducted jointly by a neuroradiologist with 15 years of experience and a rhinology-trained otolaryngologist with 10 years of experience. Notably, the radiologist was not blinded to the patients' acromegaly status.

The evaluated parameters included: (Figure 1)

- Number of sphenoid septa, septal attachment, and pneumatization types.
- Protrusion and dehiscence of the internal carotid artery, optic nerve, maxillary nerve, and Vidian nerve.
- Intercarotid distance (ICD): Defined as the shortest distance between the medial walls of the internal carotid arteries, measured on axial CT images at the level of the clinoid segment above the cavernous sinus.
- Onodi cell – The most posterior ethmoid air cell extending close to the optic nerve, positioned laterally and superiorly to the sphenoid sinus.

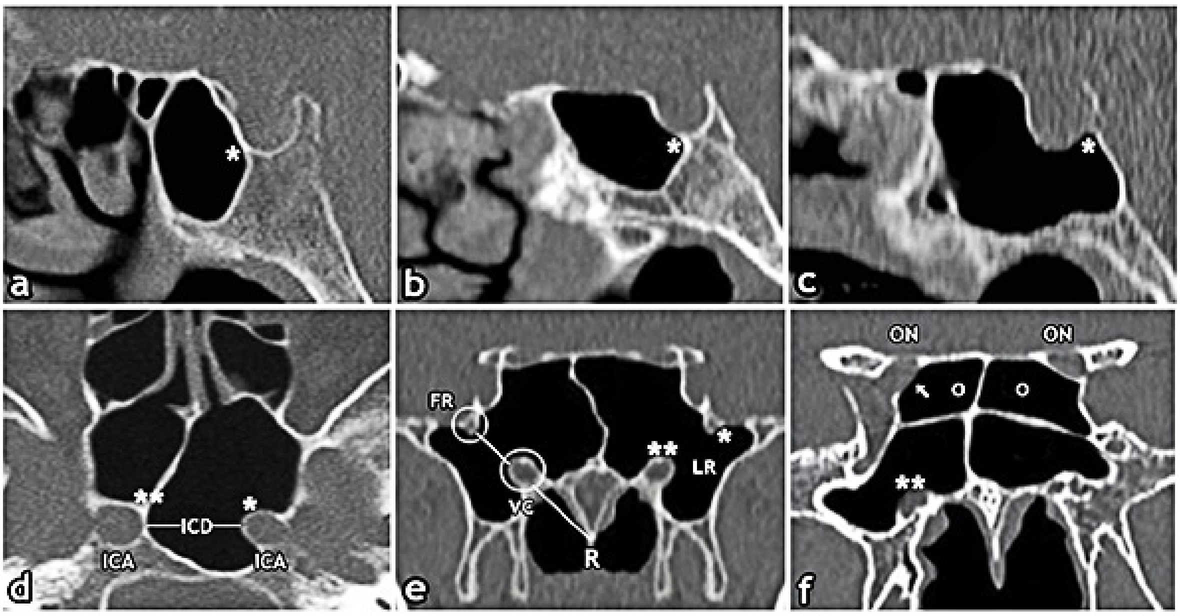

Figure 1 (a) Pre-sellar type of sphenoid sinus pneumatization. (b) Sellar type of sphenoid sinus pneumatization. (c) Post-sellar type of sphenoid sinus pneumatization. (d) Sphenoid septum attaching to the right internal carotid artery (ICA, indicated by double asterisks**), with the left ICA showing protrusion and dehiscence (single asterisk*); intercarotid distance (ICD) is marked. (e) Relationship and measurements between the foramen rotundum (FR), Vidian canal (VC), and sphenoid rostrum (R); maxillary nerve (double asterisks**) and Vidian nerve (single asterisk*) protrusions are highlighted, along with the lateral recess (LR) of the sphenoid sinus. (f) Right optic nerve (ON) dehiscence (white arrow), presence of Onodi cell (O), and Vidian nerve dehiscence (double asterisks**)

• Lateral recess of the sphenoid sinus – An air cavity extending beyond the line connecting the Vidian canal and foramen rotundum.

• Sphenoid rostrum–Vidian canal distance (R-VC) – The distance between the Vidian canal opening and the sphenoidal rostrum (base of the sphenoid sinus).

• Sphenoid rostrum–Foramen rotundum distance (R-FR) – The distance between the foramen rotundum and the sphenoidal rostrum.

• Foramen rotundum–Vidian canal distance (FR-VC) – The distance between the foramen rotundum and the Vidian canal opening within the sphenoid sinus.

The radiologist was not blinded to the patients' acromegaly status.

Results

This study included patients with hormone-secreting pituitary adenomas, categorized into acromegaly and non-acromegaly groups, who were treated at the Neurosurgery Outpatient Department of Songklanagarind Hospital between January 1, 2012 and December 31, 2022. A total of 150 patients were analyzed, comprising 50 acromegaly patients and 100 non-acromegaly patients, with 91 females (60.7%) and 59 males (39.3%). In the acromegaly group, the median age was 44.5 years, and the median height was 165 cm. In the non-acromegaly group, the median age was 49 years, and the median height was 160 cm. The baseline characteristics and significant differences between the two groups are summarized in Table 1. Preoperative CT scan were used to analyze the anatomical variations of the sphenoid sinus between the acromegaly and non-acromegaly groups. The principal investigator and a radiology specialist assessed these scans to evaluate the sphenoid sinus and its adjacent structures.

The findings demonstrated that patients with hormone-secreting pituitary adenomas associated with acromegaly exhibited statistically significant anatomical differences compared to the non-acromegaly group: Post-sellar sphenoid pneumatization was significantly more common in the acromegaly group (p-value=0.002). Sphenoid septum attachment to the optic nerve was more frequently observed in acromegalic patients (p-value=0.018). The presence of an Onodi cell, indicating posterior ethmoid air cell extension into the sphenoid sinus, was significantly associated with acromegaly (p-value=0.011). The distance between the sphenoid rostrum and the Vidian canal was significantly greater in the acromegaly group, with mean distances of 15.8 mm (right) and 16.5 mm (left) compared to the non-acromegaly group (p-value<0.001 and p-value=0.008, respectively). These findings are detailed in Table 2.

Further analysis of the sphenoid sinus and its adjacent structures using CT imaging revealed additional significant anatomical variations in acromegalic patients: Vidian nerve protrusion into the sphenoid sinus was significantly more frequent in the acromegaly group

Table 1 Baseline characteristics of patients with and without acromegaly in hormone-secreting pituitary adenomas

Characteristic	Acromegaly (n=50)	Non acromegaly (n=100)	p-value
Patient characteristic			
Age, median (IQR), year	44.5 (37,53.8)	49 (40.8,55)	0.206*
Gender			0.768&
Male (%)	21 (42%)	38 (38%)	
Female (%)	29 (58%)	62 (62%)	
Height, median (IQR), cm	165 (155,168)	160 (155,165)	0.148*

*Ranksum test, &Chi-square

Table 2 Comparison of sphenoid sinus anatomical differences in patients with hormone-secreting pituitary adenomas With and without acromegaly

Anatomical data	Acromegaly (n=50)	Non acromegaly (n=100)	p-value
Number of sphenoid septum			0.045§
1	45 (90%)	94 (94%)	
2	4 (8%)	5 (5%)	
>2	1 (2%)	1 (1%)	
Sphenoid septum attachment			0.018§
Attachment to optic nerve	4 (8%)	0	
Attachment to carotid artery	10 (20%)	19 (19%)	
Type of sphenoid pneumatization			0.002§
Sellar type	7 (14%)	39 (39%)	
Pre-sellar type	1 (2%)	3 (3%)	
Post-sellar type	42 (84%)	58 (58%)	
Onodi cell	23 (46%)	53 (53%)	0.011&
Lateral recess of sphenoid sinus	27 (54%)	63 (63%)	0.377&
R-FR distance			
Rt. median (IQR),mm	23.4 (21.5,26.3)	23.7 (22.2,25.3)	0.745*
Lt. median (IQR),mm	24.9 (23,26.3)	24.6 (22.6,26.3)	0.6*
R-VC distance			
Rt. median (IQR),mm	16.5 (2.6)	14.7 (1.9)	<0.001#
Lt. median (IQR),mm	15.8 (14.5,17.8)	14.9 (13.5,16)	0.008*
FR-VC distance			
Rt. median (IQR),mm	4.9 (2.7,8.2)	6.2 (4.1,8)	0.075*
Lt. median (IQR),mm	5.5 (3.8,8.6)	6.6 (5,8.2)	0.313*
Protrusion	38 (76%)	35 (35%)	<0.001&
Dehiscence	12 (24%)	9 (9%)	
ICA			0.025&

#T-test, §Fisher's exact test, *Ranksum test, &Chi-square, R-VC distance=sphenoid rostrum–Vidian canal distance, R-FR distance=sphenoid rostrum–foramen rotundum distance, FR-VC distance=foramen rotundum–vidian canal distance

(p-value=0.013). Optic nerve protrusion into the sphenoid sinus was also significantly observed (p-value<0.001). Optic nerve dehiscence (absence of a bony covering over the optic nerve) was significantly higher in the acromegaly group (p-value=0.025). Internal carotid artery dehiscence (exposure of the artery without a bony covering) was significantly more common (p-value=0.034). The intercarotid distance, which represents the space between the internal carotid arteries within the cavernous sinus, was significantly narrower in acromegalic patients, averaging 16.4 mm (p-value<0.001). These findings are summarized in Table 3.

Table 3 Comparison of anatomical differences of key Structures adjacent to the sphenoid sinus in patients with hormone-secreting pituitary adenomas with and without acromegaly

Anatomical data	Acromegaly (n=50)	Non acromegaly (n=100)	p-value
Maxillary nerve			
Protrusion	32 (64%)	47 (47%)	0.523&
Dehiscence	3 (6%)	0	0.036§
Vidian nerve			
Protrusion	34 (68%)	45 (45%)	0.013&
Dehiscence	3 (6%)	2 (2%)	0.334§

Discussion

The findings from this study highlight significant anatomical differences in the sphenoid sinus and adjacent structures between acromegalic and non-acromegalic patients with hormone-secreting pituitary adenomas, consistent with previous studies[7,8]. These anatomical variations have direct implications for transsphenoidal surgery, which remains the standard approach for pituitary adenoma resection[9].

Patients with acromegaly demonstrated a higher prevalence of post-sellar sphenoid pneumatization, which can alter the trajectory of the surgical corridor and affect the stability of the bony landmarks used for intraoperative navigation[10]. Additionally, a greater incidence of sphenoid septum attachment to the optic nerve increases the risk of inadvertent optic nerve injury during sphenoidotomy or septum removal[11]. The presence of Onodi cells, which extend posteriorly into the sphenoid sinus, further complicates surgical access by increasing the risk of optic nerve damage, particularly in cases requiring extensive sphenoid sinus drilling[12,13].

Furthermore, acromegalic patients exhibited greater sphenoid rostrum-to-Vidian canal distance, which suggests an increased pneumatization of the sphenoid sinus. This finding implies that in acromegalic patients, the bony support surrounding the vital neurovascular structures, such as the internal carotid artery (ICA) and optic nerve, may be thinner or absent, increasing the likelihood of dehiscence.[(14)] The significantly higher occurrence of optic nerve and ICA dehiscence in the acromegalic group underscores the necessity for meticulous surgical dissection to prevent catastrophic vascular or neural injury.

Given these anatomical variations, transsphenoidal surgery in acromegalic patients presents greater complexity and requires enhanced preoperative planning. Surgeons must be aware of these anatomical alterations to optimize surgical outcomes and minimize complications.

The anatomical differences observed in this study may be explained by the prolonged exposure of acromegalic patients to excess growth hormone (GH) and insulin-like growth factor-1 (IGF-1), which influence bone remodeling and craniofacial structural changes[15].

Previous studies have demonstrated that GH excess leads to hyperostosis, increased bone volume, and cortical thickening, particularly in the skull base and facial bones[5,6]. The findings of this study, including greater sphenoid sinus pneumatization, narrowed intercarotid distance, and increased protrusion of neurovascular structures into the sinus cavity, align with this pattern of GH-induced cranial remodeling. These changes may be attributed to a GH-mediated expansion of pneumatized spaces in the skull base and progressive medialization of the carotid arteries, possibly due to increased bone growth and subsequent remodeling of the sellar and parasellar regions.

Comparative studies have shown that acromegalic patients exhibit significantly narrower intercarotid distances than non-acromegalic patients, as demonstrated by Carrabba et al.[2] and Lo Bue et al.[8] The present study corroborates these findings, reinforcing the notion that prolonged GH exposure contributes to progressive alterations in the spatial arrangement of critical vascular structures. Additionally, the higher prevalence of ICA dehiscence in acromegalic patients supports the hypothesis that sustained GH and IGF-1 activity may lead to thinning of the bony walls surrounding major blood vessels, increasing susceptibility to intraoperative vascular injury.

Understanding these long-term GH-induced skull base changes is essential for both endocrinologists and neurosurgeons, as it highlights the importance of early diagnosis and treatment of acromegaly to prevent excessive craniofacial and skull base remodeling, which could complicate future surgical interventions.

Given the unique anatomical alterations in acromegalic patients, modifications to the standard transsphenoidal surgical approach should be considered to optimize safety and efficacy.

Preoperative imaging and surgical planning

Due to the high prevalence of ICA and optic nerve dehiscence in acromegalic patients, thin-slice CT imaging with detailed bone window reconstructions should be performed in all cases. This allows precise identification of critical neurovascular structures, dehiscent areas, and variations in sphenoid sinus pneumatization before surgery. MRI should be used to complement CT findings, particularly for assessing tumor invasion into the cavernous sinus[16].

Modified surgical entry techniques

In cases with extensive post-sellar sphenoid pneumatization, surgeons should avoid excessive drilling near the sellar floor, as the bony structures may be thin and fragile. A wider bone opening may be necessary to accommodate anatomical distortions, particularly in patients with narrow intercarotid distances, to avoid excessive traction on the ICA.

When sphenoid septations are attached to the optic nerve, septum removal should be approached cautiously using a burr or ultrasonic aspirator rather than aggressive curettage, reducing the risk of traction injury to the nerve. Similarly, the presence of Onodi cells necessitates careful drilling near the posterior ethmoid region to prevent optic nerve damage.

Consideration for alternative approaches

In select cases where the transsphenoidal corridor is highly distorted, extended transsphenoidal approaches or combined transcranial and endoscopic techniques may be considered. These may provide better access to deep-seated tumors while avoiding high-risk areas with dehiscent neurovascular structures[17].

Intraoperative monitoring and navigation

The use of intraoperative neuronavigation and Doppler ultrasound can aid in real-time localization of the ICA and optic nerve, reducing the likelihood of inadvertent injury. Electrophysiological monitoring of the optic nerve may also be beneficial in high-risk cases where nerve compression or manipulation is anticipated[18]. By implementing these modifications, the risk of neurovascular complications, excessive bleeding, and postoperative visual deficits can be minimized, ultimately leading to improved surgical outcomes in acromegalic patients undergoing transsphenoidal pituitary surgery.

Strengths and limitations

The major strength of this study lies in its relatively large sample size and detailed anatomical assessment through high-resolution CT imaging. These factors enhance the robustness of the anatomical comparisons between acromegalic and non-acromegalic patients.

However, several limitations should be acknowledged. First, the retrospective, single-center design introduces potential selection bias, which may limit the generalizability of the findings. Second, the radiologist involved in the assessment was not blinded to the patients' acromegaly status, which could have introduced observer bias during image interpretation. Additionally, interobserver variability was not assessed, which may affect the reproducibility of the findings. Our study also lacked longitudinal outcome data, and we were unable to assess whether the observed anatomical differences correlated with actual surgical risks or postoperative complications. Future prospective multicenter studies with blinded image evaluation, interobserver reliability assessment, and integration of surgical outcome data are recommended to validate these findings and further refine surgical strategies for acromegalic patients.

Conclusion

This study highlights the significant anatomical differences in the sphenoid sinus and adjacent structures in acromegalic patients, which have direct implications for transsphenoidal surgical planning and execution. These findings emphasize the necessity for enhanced preoperative imaging, meticulous intraoperative techniques, and tailored surgical approaches to navigate the anatomical challenges unique to this patient population. While individualized imaging remains critical in clinical practice, understanding population-specific anatomical trends provides an additional layer of preoperative awareness and risk anticipation. By integrating these considerations into clinical workflows, neurosurgeons can improve patient safety and optimize outcomes in pituitary adenoma surgery for acromegalic patients.

Ethics approval

This retrospective study was approved by the Human Research Ethics Committee of the Faculty of Medicine, Prince of Songkla University (Approval No. EC66-183-13-1). Informed consent was waived due to the retrospective nature of the study.

Informed consent

The ethics committee waived the requirement for informed consent due to the retrospective design of the study.

Data and material

Database of Faculty of Medicine, Prince of Songkla University.

Conflict of interest

The author declares that there are no competing interests. No author has any proprietary interest in any of the products or ideas mentioned in this article.

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Authors' contributions

P.C. and P.W. were responsible for the study design, data extraction, data analysis, literature review, and manuscript drafting. N.S. reviewed the imaging data. V.K. and U.P. contributed to the manuscript review and revisions. All authors read and approved the final version of the manuscript.

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