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Evaluation of the Anatomical Variations of Paranasal Sinus Region by Multidetector Computed Tomography

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ABSTRACT

Background: This study aims to evaluate the prevalence of anatomical variations in the paranasal sinus (PNS) region and assess their clinical relevance, particularly concerning sinusitis and surgical implications, using Multidetector Computed Tomography (MDCT).

Methods: A prospective observational study was conducted over one year in the Department of Radiodiagnosis, NRI Institute of Medical Sciences, Visakhapatnam, Andhra Pradesh, India. A total of 142 adult patients (73 females and 69 males; mean age 34.2 years) referred for MDCT of PNS for suspected sinus pathology were included. Axial scans (0.625 mm slice thickness) and coronal reconstructions were analysed for anatomical variants and mucosal abnormalities, following standard protocols.

Results: Anatomical variations were identified in 124 patients (87.3%). The most prevalent were deviated nasal septum (54.3%) and middle concha bullosa (46.5%). Other variations included paradoxical middle turbinate (13.4%), Haller cells (7%), and Onodi cells (2%). Mucosal abnormalities suggestive of sinusitis were observed in 94 patients (66%). Variants were present in 77.5% of those with sinusitis and 87.5% of those without. Maxillary sinusitis was most common (49%). High-risk variations such as dehiscent optic nerve (Type II/III: 7–10%) and asymmetric ethmoid roofs (Keros Type II: 78.9%) were noted.

Conclusion: Anatomical variants in the PNS are common but do not inherently cause sinusitis. However, recognizing them is critical for surgical safety in Functional Endoscopic Sinus Surgery (FESS). Preoperative MDCT serves as an essential tool in minimizing complications and optimizing surgical outcomes.

Key-words: Multidetector Computed Tomography, Paranasal Sinuses, Anatomical Variations, Functional Endoscopic Sinus Surgery, Sinusitis, Preoperative Planning

INTRODUCTION

Having a solid grasp of paranasal sinus anatomy and its variations is crucial for clinicians, especially with the rise of functional endoscopic sinus surgery (FESS).

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While there's ongoing debate about how these anatomical differences might block the osteomeatal complex (OMC) and lead to chronic sinusitis, recognizing them is essential for ensuring safe surgical procedures [1]. Risks like cerebrospinal fluid (CSF) leaks, orbital injuries, and harm to vital structures such as the anterior ethmoidal artery are significant concerns during FESS, highlighting the importance of thorough preoperative anatomical mapping. Traditional radiography has been replaced by computed tomography (CT) as the go-to imaging technique for assessing the paranasal sinuses,

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thanks to its superior contrast resolution and ability to reveal subtle changes in bone and soft tissue with remarkable accuracy [2,3].

CT serves as a vital "anatomical road map," clearly outlining the intricate osteomeatal anatomy and its three main components—air spaces, soft tissues, and bony walls—allowing for reliable identification of anatomical variations and pathologies. The rise and widespread use of FESS and similar procedures have only increased the need for high-quality imaging to aid in surgical planning and reduce the chances of complications during and after surgery [4,5].

MDCT marks a major leap forward in imaging technology. It allows for quick capture of thin slices and offers the ability to create multiplanar reformations (MPR) and three-dimensional (3D) reconstructions from axial data. This capability provides an exceptional view of the complex anatomy of the sinuses from any angle, which is crucial for spotting variations and assessing how far disease has spread into nearby areas like the orbit or skull base [6].

While magnetic resonance imaging (MRI) is great for detailing soft tissues, CT scans are still the go-to choice for examining the mostly bony structure of the paranasal sinuses. Because of this, getting a preoperative CT scan has become a standard practice before sinus surgery, ensuring that both the pathology and important anatomical variations are thoroughly understood. Common variations include things like septal deviations, concha bullosa, variations in the uncinate process, and different configurations of ethmoid air cells (like agger nasi, Haller, and Onodi cells), as well as sinus hypoplasia and asymmetries. It's also crucial to be aware of related anatomy, such as the path of the optic nerve and any asymmetries in the ethmoid roof [7,8].

Even though many CT studies tend to focus on patients suspected of having sinusitis, there's still a gap in comprehensive evaluations of anatomical variations in broader populations, including those without any inflammatory issues, and how these variations might differ by gender and age. This study, carried out at NRI Institute of Medical Sciences, Visakhapatnam, Andhra Pradesh, aims to use MDCT to systematically explore the range and frequency of anatomical variations in the paranasal sinus area, look at their occurrence in both sinusitis patients and those without, and investigate any potential links to gender and age.

MATERIALS AND METHODS

Study Design and Setting- This prospective observational study took place at the NRI Institute of Medical Sciences, Visakhapatnam, Andhra Pradesh, India, spanning a year from April 2023 to March 2024. Before we got started, we made sure to secure ethical approval from the hospital's institutional review board.

Study Population and Selection Criteria- Our study included a group of adult patients (18 years and older) who were referred from the Department of Otorhinolaryngology to the Department of Radiodiagnosis for MDCT of the paranasal sinuses. This was due to clinical suspicions of sinus issues or a history of sinusitis. We obtained written informed consent from all participants after thoroughly explaining the study. We excluded pregnant women and those with a history of facial trauma, road traffic accidents, sinonasal malignancy, or previous surgeries involving the paranasal sinuses. A pre-scan evaluation confirmed the clinical need for the MDCT.

MDCT Imaging Protocol- All scans were conducted using a GE 16-slice MDCT scanner without any intravenous contrast. Patients were positioned lying on their backs, with the gantry set perpendicular to the hard palate. The scan covered the area from the front of the frontal sinus to the back of the sphenoid sinus. The acquisition parameters were set as follows: slice thickness of 0.625mm, collimation of 16x0.625 mm, increment of 10.0 mm, kilovoltage at 120kVp, and milliamperes at 250mA. We used both soft tissue and bone reconstruction algorithms. Axial images were systematically captured for all patients, and we also included coronal plane reconstructions for a more comprehensive view.

Image Analysis and Data Collection- We took a close look at all MDCT images, carefully reviewing them through both soft tissue and bone density windows. Using a standardized form, we meticulously noted the presence or absence of specific anatomical variations in the paranasal sinus region. The variations we evaluated included nasal septal deviation and bony spurs, as well as turbinate variations like superior concha bullosa, middle concha bullosa, paradoxical middle turbinate, turbinate hypoplasia, and secondary middle turbinate. We also examined variations in the uncinate process, such as

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deviations of the upper edge and pneumatization, along with ethmoid air cell variations like agger nasi cells, Haller cells, the great ethmoid bulla, and Onodi cells. Other variants we looked at included maxillary sinus hypoplasia, maxillary sinus septa, frontal sinus hypoplasia, and asymmetry in the sphenoid sinus cavity. Additionally, we assessed related anatomical features, including the course of the optic nerve, any asymmetry in the ethmoidal roof, and the pneumatization of the crista galli. We also documented the presence of sinusitis, whether it was frontal, ethmoidal, maxillary, sphenoidal, or pansinusitis.

Statistical Analysis- The data we collected on the standardized form, which included demographic details like age and sex, clinical diagnoses, and comprehensive imaging findings for each anatomical variant, were entered into a Microsoft Excel spreadsheet. This database became the backbone for our statistical analysis, allowing us to evaluate how frequently these anatomical variations occurred, compare their prevalence between patients with and without sinusitis, and explore any potential links to age and gender.

RESULTS

During the 12-month study period, we had a total of 142 patients who met the inclusion criteria. This group included 73 females (51.5%) and 69 males (48.5%). When we looked at the age distribution, we found that younger adults were more prevalent, with 67 patients (47.1%) falling in the 18–30 age range. Next, there were 33 patients (23.2%) aged 31–40 years, followed by 16 patients (11.2%) in the 51–60 age group, 15 patients (10.5%) aged 41–50 years, and finally, 11 patients (7.7%) who were over 61 years old (Table 1).

Table 1: Demographic Distribution of Study Participants (n=142)

Characteristic	Category	n (%)
Gender	Female	73 (51.5%)
	Male	69 (48.5%)
Age Group (Years)	18–30	67 (47.1%)
	31–40	33 (23.2%)
	41–50	15 (10.5%)
	51–60	16 (11.2%)
	>61	11 (7.7%)

We found mucosal abnormalities that suggest sinusitis in 94 patients, which is about 66%. The maxillary sinus was the most commonly affected, showing involvement in 49% of cases (70 patients), followed by the anterior ethmoid at 34.4% (49 patients), frontal sinuses at 20.5% (29 patients), posterior ethmoid at 13.3% (19 patients), and sphenoid sinuses at 3.5% (5 patients). Pansinusitis was noted in 13 patients, making up 9% of the total. Additionally, we detected anatomical variations in 124 patients, which is 87.3% of the group. Among those with sinusitis, 77.5% (73 patients) had variants, while 87.5% (42 patients) of those without sinusitis also showed variations (Table 2).

Table 2: Mucosal Abnormalities and Anatomical Variations (n=142)

Parameter	n (%)
Mucosal Abnormalities	94 (66%)
- Maxillary sinus	70 (49%)
- Anterior ethmoid	49 (34.4%)
- Frontal sinus	29 (20.5%)
- Posterior ethmoid	19 (13.3%)
- Sphenoid sinus	5 (3.5%)
- Pansinusitis	13 (9%)
Anatomical Variations	124 (87.3%)
- With sinusitis (n=94)	73 (77.5%)
- Without sinusitis (n=48)	42 (87.5%)

A deviated nasal septum (DNS) was found to be the most common variant, occurring in 54.3% of cases (n=77), with Type I being the most frequent at 51.7% (n=40). Following that, we observed middle concha bullosa in 46.5% of cases (n=66). Other variants included a paradoxical middle turbinate at 13.4% (n=19), a curved uncinate process at 14.7% (n=21), and Haller cells at 7% (n=10). When we looked at the optic nerve course, Type I was the most prevalent, showing up in 82.3% on the right side and 90% on the left, while Type IV was quite rare at just 0.7% on the right. As for the asymmetry of the ethmoidal roof, according to the Keros classification, Type II was the most common, appearing in 78.9% of cases (n=112) (Table 3).

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Table 3: Anatomical Variations and Subtype Distributions

Variant	n (%)	Subtypes (n, %)
Deviated Nasal Septum	77 (54.3%)	Type I: 40 (51.7%)
		Type V: 15 (19.4%)
		Type II: 8 (10.3%)
		Type III: 7 (9%)
Middle Concha Bullosa	66 (46.5%)	-
Optic Nerve Course	-	Type I (Right/Left): 117/126
		Type II (Right/Left): 14/10
		Type III (Right/Left): 10/6
Ethmoidal Roof (Keros)	-	Type II: 112 (78.9%)
		Type I: 29 (20.4%)

Fig. 1 presents the CT topogram used for paranasal sinus planning and scan range. Fig. 2 shows a coronal CT section with bilateral middle concha bullosa, more prominent on the right, along with mild left maxillary sinusitis. Fig. 3 depicts left-sided concha bullosa, a deviated nasal septum (DNS) towards the left, and a pneumatized crista galli. Fig. 4 highlights a bifid right middle turbinate with paradoxical curvature and a pneumatized uncinate process on the left. Fig. 5 illustrates prominent Agger Nasi cells bilaterally, which may impact frontal sinus drainage. Fig. 6 reveals a right-sided Haller's cell, bilateral middle concha bullosa, and associated ethmoidal and maxillary sinusitis, more on the left. Fig. 7 demonstrates bilateral pneumatization of the lesser wing of the sphenoid bone. Fig. 8 displays a pneumatized right anterior clinoid process and a Type III optic nerve course, with partial dehiscence of the optic nerve into the sphenoid sinus. Fig. 9 captures a deviated nasal septum with a left-sided bony spur (Type V). Fig. 10 shows a hypoplastic left frontal sinus, contributing to frontal sinus drainage alteration.

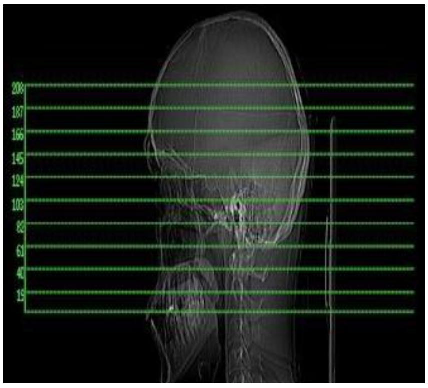

Fig. 1: CT scan PNS. Topogram and planning

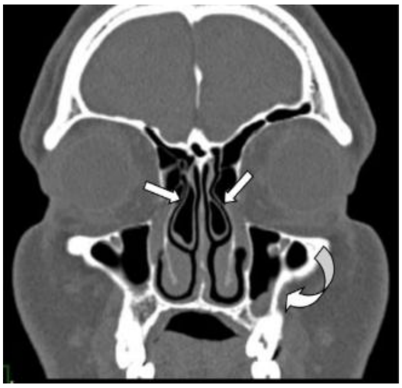

Fig. 2: CT scan PNS coronal section showing bilateral middle concha bullosa- right larger than left (arrows)with mild left maxillary sinusitis (curved arrow).

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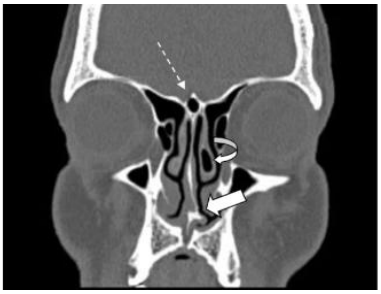

Fig. 3: CT scan PNS coronal section showing concha bullosa on the left side (Curved arrow). DNS to the left side (Arrow) and pneumatised crista galli (Dash arrow)

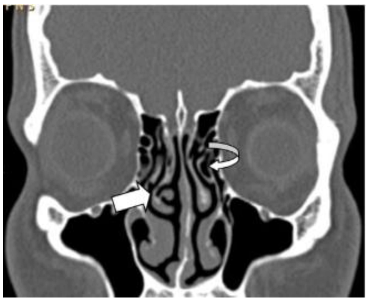

Fig. 4: CT scan PNS coronal section showing bifid right middle turbinate with paradoxical curvature (arrow) and pneumatised uncinate process on left side (curved arrow)

Fig. 5: CT scan PNS coronal section showing prominent Agger Nasi cells on both sides (arrows)

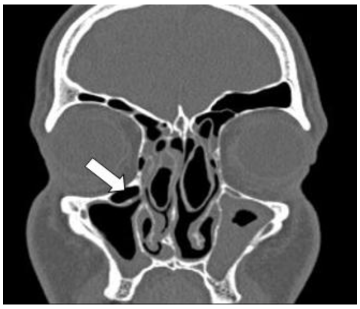

Fig. 6: CT scan PNS coronal section showing Haller's cell on the right side (arrow) with bilateral middle concha bullosa with bilateral maxillary (L>R) and ethmoidal sinusitis

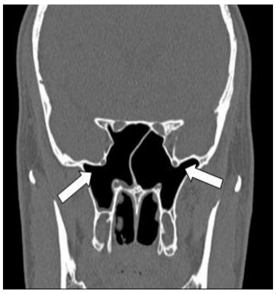

Fig. 7: CT scan PNS coronal section showing pneumatization of lesser wing of sphenoid bone on both sides (arrows)

Fig. 8: CT scan PNS coronal section showing pneumatized right anterior clinoid process and type III optic nerve course. Part of the optic nerve (arrow) is exposed to air in the sphenoidal sinus

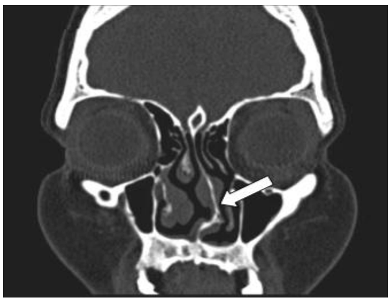

Fig. 9: CT scan PNS coronal section showing DNS with spur (type v) to left side

Fig. 10: CT scan PNS coronal section showing hypoplastic left Frontal sinus (arrow)

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DISCUSSION

This MDCT study reveals that anatomical variations in the paranasal sinuses are quite common, showing up in 87.3% of cases. The most frequently observed variations include a deviated nasal septum at 54.3% and middle concha bullosa at 46.5%. These results are in line with what's been reported in the literature, although the incidence rates can differ significantly from one study to another. For instance, the occurrence of concha bullosa has been reported to range from 16% (Dua *et al.*) [9] to 53.6%, while our finding of 46.5% highlights the differences in how pneumatization is defined across studies. Additionally, we found that paradoxical middle turbinate (13%) and Haller cells (7%) were consistent with previous findings (Perez-Pinas *et al.* 10% [1]; Kennedy and Zinreich [8]: 10%). These variations, including Onodi cells (2%) and uncinate process pneumatization (3.7%), could potentially obstruct the osteomeatal complex, hinder mucociliary clearance, and increase the risk of sinusitis.

Interestingly, we noted that anatomical variants were present in 77.5% of patients with sinusitis and 87.5% of those without it. This aligns with the conclusions of Bolger *et al.* [10] and Stammberger [11], who suggested that these variants don't directly cause issues but may contribute as co-factors when inflammation or infection is present. The high prevalence of these variants in asymptomatic individuals raises questions about a direct causal relationship, supporting the idea that they are common anatomical features rather than isolated causes of disease. For example, while a severe septal deviation can block drainage, its occurrence in asymptomatic cases (like the 58% noted by Bent *et al.*) indicates that factors such as mucosal hypertrophy or immune responses play a significant role [12,13].

Despite advancements, identifying anatomical variations before surgery is crucial for ensuring patient safety. Variants such as Onodi cells (which pose a risk of optic nerve injury), dehiscent optic nerve canals (Type II/III: 7–10%), and asymmetric ethmoid roofs (Keros type II: 78.9%) can significantly increase the risks during surgery. The rare occurrence of a Type IV optic nerve course—where the nerve runs unprotected through the sphenoid sinus—illustrates a high-risk scenario that requires careful planning [14,15]. Additionally, Haller cells can constrict the maxillary ostium, and the presence of aerated crista galli (8.5%) may complicate approaches to the anterior skull base [16].

In summary, while anatomical variations are common and their connection to sinusitis is still up for debate, their influence on surgical outcomes is clear. Radiologists need to thoroughly assess and communicate these variations to inform functional endoscopic sinus surgery (FESS), reduce risks (like orbital injuries and CSF leaks), and enhance the chances of successful treatment.

CONCLUSIONS

This study highlights the crucial role of Multidetector Computed Tomography (MDCT) in assessing the anatomy of the paranasal sinuses before surgery. It uncovers a significant number of anatomical variations, with the deviated nasal septum appearing in 54.3% of cases and middle concha bullosa in 46.5%. These variations are found in both symptomatic (77%) and asymptomatic (85%) individuals. While they don't directly cause sinus issues, recognizing them is vital for ensuring surgical safety, as they can increase risks during functional endoscopic sinus surgery (FESS). MDCT provides a comprehensive anatomical map that helps radiologists inform surgeons about potential high-risk variations, such as Onodi cells and dehiscent optic nerve canals. This proactive approach can reduce complications during surgery and improve patient outcomes. Therefore, incorporating preoperative MDCT into standard care is essential for enhancing surgical accuracy and ensuring patient safety.

CONTRIBUTION OF AUTHORS

Research concept- Vineet Wadhwa, Sravan Krishna Reddy Annadevula
Research design- Vineet Wadhwa, Nutakki Sowjanya
Supervision- Lalita Wadhwa
Materials- Vineet Wadhwa, Saad Khan Mayana
Data collection- Nutakki Sowjanya, Saad Khan Mayana
Data analysis and interpretation- Vineet Wadhwa, Sravan Krishna Reddy Annadevula
Literature search- Nutakki Sowjanya, Saad Khan Mayana
Writing article- Vineet Wadhwa, Sravan Krishna Reddy Annadevula
Critical review- Lalita Wadhwa
Article editing- Vineet Wadhwa, Sravan Krishna Reddy Annadevula
Final approval- Lalita Wadhwa

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