JAS Journal of
Anatomical Sciences
UP Chapter of the Anatomical Society of India

JAS

Also available online at
www.jaypeejournals.com
www.asiupjas.com

Editor-in-Chief
Satyam Khare

From Dissection to Digitization: Reimagining Anatomy Education with Interactive Software

Shilpi Jain

Anatomy has always been considered the foundation of medical education. For generations, medical students have entered the dissection hall with a sense of awe, the cadaver being their "first patient." Yet, in recent years, the narrative has begun to shift. Alongside the smell of formalin and the tactile feel of tissues, students are now equally likely to be greeted by glowing screens and 3D reconstructions. The rise of digital software in anatomy teaching is not a passing experiment—it is slowly reshaping how MBBS students encounter the human body.

The reasons are easy to see. Modern anatomy software can rotate a skull in three dimensions. They can also peel away muscle layers with a click, or replay blood flow through a beating heart. For a first-year student struggling with the sheer volume of structures to memorize, these tools may provide a clarity that traditional atlases and chalkboard sketches cannot.[1] Virtual reality (VR) platforms, for example, allow learners to "step inside" the cranial cavity or trace the branching of coronary arteries in an immersive way.[2] Such experiences often appear to accelerate spatial understanding, particularly for those who find it difficult to translate two-dimensional textbook images into three-dimensional mental maps.

Still, there is an unease that lingers. Does this digital shift risk sidelining cadaveric dissection, long considered irreplaceable in medical training? Some educators argue that software can never replicate the texture and unpredictability of a real human body.[3] The absence of this tactile engagement may leave graduates less confident in the operating room or clinical practice. Others counter that the availability of cadavers is declining in many institutions, and software may serve as a pragmatic bridge.[4] Perhaps the real question is not whether software should replace dissection, but how the two can coexist in a complementary fashion.

Another concern lies in over-reliance. While anatomy apps are designed to be interactive, there is a risk that students may adopt a passive, "scroll-and-swipe" style of learning. Unlike dissection, which forces active problem-solving and teamwork, digital platforms can sometimes foster solitary or superficial engagement. Faculty involvement becomes critical here. When software is thoughtfully integrated—say, used before a dissection to preview a region, or afterward to consolidate knowledge—students appear to gain the most benefit.[5]

Cost and accessibility also deserve attention. Not all medical colleges can afford high-end VR systems or institutional licenses for premium software. A well-funded private institution may provide its students with headsets and subscriptions, while a government college in a smaller city may struggle to provide

Department of Anatomy, Subharti Medical College, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India
Corresponding Author: Shilpi Jain, Department of Anatomy, Subharti Medical College, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India, Phone: +91 9927009518, e-mail: j.vidisha@yahoo.in

even a handful of shared workstations. The digital divide, if left unchecked, risks widening disparities in anatomy education across the country.[6]

At the same time, we cannot ignore the changing expectations of today's learners. This is a generation accustomed to interactive media and zooming to make sense of complex information. To expect them to learn solely through black-and-white diagrams may be unrealistic. Digital anatomy tools, if used wisely, may help sustain attention and foster self-directed learning. They can also support repeated practice—rewinding and replaying concepts that, in the dissection hall, are often a one-time opportunity.

Where does this leave us? Perhaps in a position of cautious optimism. Digital software, when seen not as a replacement but as a partner to traditional anatomy teaching, holds the potential to enrich learning. It may not carry the same emotional weight as the first incision on a cadaver, but it offers something equally valuable: Flexibility and accessibility. The future of anatomy education, then, may not be about choosing between dissection and digitization, but about weaving them together in ways that honor both tradition and innovation.

As educators, we carry a responsibility to experiment without losing sight of what matters most. Software will continue to evolve—AI-based anatomy tutors, and even holographic projections, may soon become commonplace. But in the end, the goal remains the same as it always was: To help the next generation of doctors understand the human body in all its complexity, and to prepare them for the patients who will one day depend on that knowledge.

References

1. Sugand K, Abrahams P, Khurana A. The anatomy of anatomy: A review for its modernization. Anat Sci Educ 2010;3(2):83–93. DOI: 10.1002/ase.139.

2. Moro C, Štromberga Z, Raikos A, et al. The effectiveness of virtual and augmented reality in health sciences and medical anatomy. Anat Sci Educ 2017;10(6):549–559. DOI: 10.1002/ase.1696.

3. Turney BW. Anatomy in a modern medical curriculum. Ann R Coll Surg Engl 2007;89(2):104–107. DOI: 10.1308/003588407X168244.

4. Aziz MA, McKenzie JC, Wilson JS, et al. The human cadaver in the age of biomedical informatics. Anat Rec 2002;269(1):20–32. DOI: 10.1002/ar.10046.

5. Estai M, Bunt S. Best teaching practices in anatomy education: A critical review. Ann Anat 2016;208:151–157. DOI: 10.1016/j.aanat.2016.02.010.

6. Mathiowetz V, Yu CH, Quake-Rapp C. Comparison of a gross anatomy laboratory to online anatomy software for teaching anatomy. Anat Sci Educ 2016;9(1):52–59. DOI: 10.1002/ase.1528.

Simulated Virtual Patients vs Hospital Setting Teaching for Early Clinical Exposure in Anatomy: A Comparative Study

Satyam Khare

Abstract

Background: Early clinical exposure (ECE) bridges theoretical anatomy with clinical practice. Traditional hospital-based teaching has been the standard but is limited by patient availability, variability in exposure, and logistical issues. Simulated virtual patients (SVPs) offer an alternative by providing standardized, interactive, and ethically sound clinical learning opportunities. This study compared the effectiveness of SVP-based learning with hospital-based ECE in anatomy, focusing on engagement, knowledge retention, clinical correlation, and confidence.

Materials and methods: A comparative cross-sectional study was conducted among preclinical medical students randomly assigned to SVP or hospital exposure groups. Data were collected using structured questionnaires, pre- and post-session assessments, and qualitative feedback. Statistical analyses included the Mann–Whitney U test, Chi-square test, and thematic analysis of open-ended responses.

Results: Simulated virtual patient-based learning significantly improved student engagement ($p = 0.002$), knowledge retention ($p = 0.001$), and ability to correlate anatomy with clinical cases ($p = 0.01861$). Confidence levels were similar in both groups ($p = 0.755$). Qualitative feedback indicated that SVPs enhanced interactivity and visualization, whereas hospital exposure provided authentic patient interaction but with limited case diversity.

Conclusions: Simulated virtual patients are effective in improving engagement, retention, and clinical application in anatomy education, though real patient exposure remains essential. A hybrid approach integrating SVPs with hospital-based learning is recommended for comprehensive training.

Keywords: Anatomy education, Clinical correlation, Early clinical exposure, Hybrid learning, Medical curriculum innovation, Medical simulation, Simulated virtual patients.

Journal of Anatomical Sciences (2025): 10.5005/jas-11049-0007

Introduction

Medical education has undergone a significant transformation in recent decades, with increasing emphasis on bridging the gap between theoretical knowledge and practical application. A key innovation in this context is early clinical exposure (ECE), which integrates clinical learning with foundational sciences such as anatomy to enhance comprehension, contextual relevance, and professional development. Early clinical exposure helps students recognize the importance of basic sciences in medical practice, reinforces long-term knowledge retention, and facilitates the development of clinical reasoning and diagnostic skills early in training.[1]

Traditionally, hospital-based exposure has been the most common mode of delivering ECE. By interacting with real patients, students learn to appreciate the clinical significance of anatomical structures, develop professional communication, and cultivate confidence in clinical reasoning.[2] However, this approach is not without limitations. Variability in patient availability, inconsistency in case exposure, ethical and privacy concerns, and logistical challenges in organizing patient rounds for large cohorts often hinder its implementation.[3] Furthermore, ethical concerns regarding patient dignity and appropriateness of early exposure to sensitive conditions further complicate the process.[4] These challenges necessitate innovative teaching approaches that provide consistency, scalability, and standardization, while still ensuring the acquisition of essential clinical skills.

Simulated virtual patients (SVPs) have emerged as a promising solution to overcome these constraints. Simulated virtual patients

Department of Anatomy, Subharti Medical College, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India

Corresponding Author: Satyam Khare, Department of Anatomy, Subharti Medical College, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India, Phone: +91 9837083748, e-mails: dr_kharesatyam@yahoo.com; satyamkhare@subharti.co

are interactive, computer-generated patient scenarios designed to replicate real-life clinical conditions. They provide students with opportunities to engage in history taking, decision-making, and problem-solving within a safe, controlled, and standardized environment.[5] Unlike real patients, SVPs can be uniformly presented to all students, ensuring equal exposure to a diverse range of cases.[6] This standardization is particularly valuable in anatomy education, where consistent exposure to clinical correlations enhances the integration of theoretical and practical knowledge.

Evidence suggests that SVPs improve student engagement, knowledge retention, and clinical reasoning skills. Virtual platforms often integrate interactive elements, including quizzes,

branching decision paths, and 3D visualization of anatomical structures, which encourage active participation and self-directed learning.[7] Such immersive experiences foster deeper understanding and contextualization of anatomy within clinical practice. Importantly, SVPs eliminate ethical concerns associated with real patient encounters and are accessible across diverse learning environments, making them suitable for both in-person and remote education.[6]

Comparative research indicates that SVP-based learning can perform on par with, or even surpass, traditional hospital-based teaching. A randomized trial by Triola et al.[8] demonstrated that students trained with virtual patients performed equally well, if not better, than those trained with live standardized patients. Similarly, Wood et al. reported that SVP learners exhibited superior clinical reasoning skills compared to peers in traditional ECE programs.[9] In the context of anatomy, Deolalikar et al.[10] highlighted that early exposure to SVPs significantly improved comprehension and application of anatomical concepts among first-year students. These findings collectively underline the potential of SVPs to enhance early medical training, particularly in disciplines where clinical correlation is fundamental.

Despite these advantages, knowledge gaps remain. Many studies have focused on short-term outcomes, leaving the long-term effects of SVP-based learning on knowledge retention and clinical competence underexplored.[5] Similarly, the ability of SVPs to cultivate hands-on procedural skills is limited, as real-world tactile experiences and direct patient interactions cannot be replicated virtually.[6,11] Student preferences and perceptions also vary; while some students value the interactivity and accessibility of SVPs, others emphasize the irreplaceable value of real patient encounters for building empathy and clinical confidence.[4,11] Furthermore, challenges related to cost-effectiveness, infrastructure requirements, and faculty adaptation must be considered before widespread curricular integration.[12]

Given these dynamics, there is growing consensus that a hybrid learning model, which integrates the strengths of SVPs with traditional hospital-based ECE, may offer the most comprehensive approach to medical training. Such a model can standardize foundational learning while still preserving the irreplaceable value of real patient interaction. This study was therefore designed to compare the effectiveness of SVPs and traditional hospital-based teaching in the context of anatomy education, focusing on student engagement, knowledge retention, confidence, and ability to correlate anatomical knowledge with clinical cases. By providing empirical evidence from a structured comparative study, the findings aim to inform future curriculum design and contribute to the evolving landscape of medical education.

MATERIALS AND METHODS

Study Design

This was a comparative cross-sectional study conducted to evaluate the effectiveness of SVPs vs traditional CS exposure in ECE for anatomy. The study aimed to assess student engagement, knowledge retention, clinical correlation, and confidence in applying anatomical knowledge. A cross-sectional design was chosen to enable simultaneous data collection and real-time comparison between the two groups while minimizing recall bias.

Study Setting and Participants

The study was conducted at a recognized medical institution among preclinical medical students enrolled in anatomy courses. Eligible participants were students in the preclinical phase of their curriculum who voluntarily consented to participate. Students were randomly allocated into two groups: One exposed to SVPs and the other to hospital-based clinical teaching.

Sample Size and Sampling Technique

Sample size estimation was performed using G*Power software, based on prior studies reporting a 10–15% expected difference in knowledge correlation scores between SVP and CS groups. At a 95% confidence interval and 80% power, the required minimum sample size was calculated as 100 students (50 per group). Random stratified sampling was employed to ensure equal representation by academic year and gender.

Inclusion Criteria

- Medical students enrolled in the preclinical phase.
- Students who voluntarily provided informed consent.
- Participants who attended complete sessions in either SVP-based or CS-based exposure.

Exclusion Criteria

- Students with prior extensive clinical exposure.
- Participants with technical difficulties preventing engagement in SVP sessions.
- Students who failed to complete post-session assessments.
- Individuals who did not consent to participate.

Learning Interventions

- Simulated virtual patient sessions: Students in the SVP group used a predesigned virtual patient platform. The system provided interactive clinical cases requiring diagnostic reasoning and stepwise clinical decision-making. The platform incorporated built-in quizzes, real-time feedback, and visual simulations, including 3D anatomical representations, to enhance conceptual clarity and engagement.
- Clinical setting exposure: The traditional hospital-based exposure included bedside teaching with real patients, supervised by clinicians. Students engaged in physical examination, patient history taking, case discussions, and group-based learning activities under faculty guidance. Exposure to diagnostic procedures and imaging was also incorporated.

Data Collection Tools

- Structured questionnaires: Standardized feedback forms captured student perceptions of engagement, confidence, understanding of clinical relevance, and ability to correlate anatomy with clinical cases. Responses were measured using Likert scales, binary options, and open-ended items.
- Knowledge retention test: Post-session multiple-choice question (MCQ) assessments evaluated recall of anatomical structures, application to clinical cases, and retention of core concepts.
- Qualitative feedback: Open-ended questions collected detailed student reflections, allowing thematic analysis of perceived advantages and limitations of each learning modality.

Ethical Considerations

Ethical approval was obtained from the Institutional Ethics Committee before study commencement. Written informed consent was obtained from all participants after providing study information sheets. Participation was voluntary, and students were informed of their right to withdraw without academic consequences. Data confidentiality was ensured through anonymized responses stored in password-protected files. Minimal risk was involved, and all CS activities adhered to infection control protocols.

Data Analysis

Quantitative data were analyzed using descriptive and inferential statistics. Continuous variables were summarized as mean ± standard deviation (SD), and categorical data as frequencies and percentages. Ordinal responses from Likert scales were expressed as median and interquartile range (IQR).

- Mann–Whitney U test was applied for comparing engagement, knowledge correlation, and other ordinal responses between groups.
- Chi-squared test was used to analyze categorical variables such as confidence levels.
- Independent t-test was planned for normally distributed data, such as post-test scores, where applicable.

Qualitative responses were analyzed thematically. Open-ended answers were coded, categorized, and analyzed using NVivo software. Recurring patterns were grouped into themes, providing insight into student experiences, advantages, and challenges with both SVP and CS modalities.

Summary of Methods

This comparative study used stratified random sampling of preclinical students to evaluate SVPs and hospital-based ECE. A combination of quantitative assessments and qualitative feedback ensured robust evaluation of engagement, knowledge retention, clinical correlation, and student perceptions. Ethical safeguards were maintained throughout, and validated analytical methods were used to ensure the reliability of findings.

RESULTS

The study compared the effectiveness of SVPs with traditional CS exposure in enhancing ECE for anatomy. Outcomes assessed included engagement levels, confidence, understanding of clinical relevance, and ability to correlate anatomical knowledge with clinical cases.

Participant Characteristics

Participants were distributed fairly between the two groups in terms of age (18–25 years) and gender, ensuring comparability.

Engagement Levels

Engagement was measured on a 5-point Likert scale. The SVP group demonstrated slightly higher mean engagement scores compared to the CS group (Table 1), though the difference was not statistically significant ($p > 0.05$).

Confidence Levels

Student confidence in applying anatomical knowledge was assessed through self-reported ratings. Both groups showed comparable confidence (Table 2) with no significant difference ($p = 0.755$).

Understanding of Clinical Relevance

Students exposed to SVPs reported significantly greater improvement in understanding the clinical relevance of anatomy (Table 3) than those in the CS group ($p = 0.00562$).

Correlation of Anatomical Knowledge with Clinical Scenarios

A key outcome measure was students' ability to correlate anatomy with clinical cases. Simulated virtual patients (Table 4) participants performed significantly better than CS participants ($p = 0.01861$).

Statistical Summary

Since most data were ordinal and non-normally distributed, the Mann–Whitney U test was employed for comparisons. The statistical summary is shown in Figure 1.

- Engagement: No significant difference ($p > 0.05$).
- Confidence: No significant difference ($p = 0.755$).
- Clinical relevance: SVP is significantly higher ($p = 0.00562$).
- Knowledge correlation: SVP significantly higher ($p = 0.01861$).

Qualitative Findings

A thematic analysis of open-ended responses revealed several insights:

- Simulated virtual patients group: Students highlighted high interactivity, enhanced visualization (especially 3D anatomy), and standardized case exposure. Reported challenges included occasional technical issues such as internet instability and navigation difficulties.
- Clinical setting group: Students valued hands-on patient interaction and the authenticity of real-world exposure. However, they noted limitations such as restricted patient availability and variability in case diversity.

Table 1: Descriptive statistics for engagement levels

Group	Mean engagement score	Standard deviation
SVP	4.2	0.8
Clinical setting	3.9	1.1

Table 2: Confidence level comparison

Group	Median confidence level	p-value
SVP	1 (Yes)	0.755
Clinical setting	1 (Yes)	0.755

Table 3: Improvement in understanding clinical relevance

Group	Mean score	p-value
SVP	4.5	0.00562
Clinical setting	4.0	0.00562

Table 4: Ability to correlate anatomy with clinical scenarios

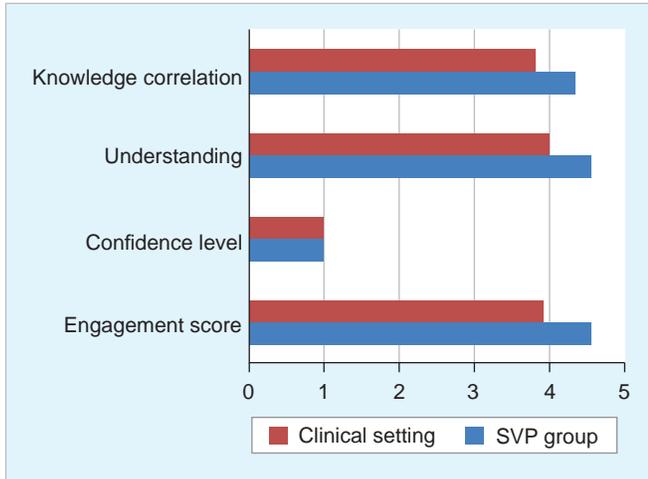| Group	Mean score	p-value
SVP	4.3	0.01861
Clinical setting	3.8	0.01861

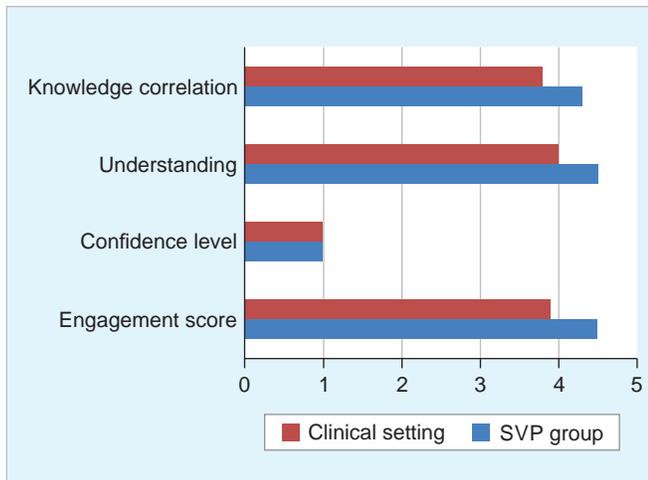**Fig. 1:** Comparison of learning outcomes: SVP vs clinical setting

Fig. 2: Comparative analysis of SVP and CS groups

Comparative Graphical Analysis

Graphical visualizations comparing SVP and CS outcomes are presented in Figure 2.

- Simulated virtual patients participants scored higher for knowledge correlation and understanding of clinical relevance.
- Engagement and confidence levels were comparable.
- Greater variability in responses was observed in the CS group, reflecting mixed experiences.

Key Findings

- Simulated virtual patients enhance knowledge correlation and clinical relevance: Students demonstrated significantly better integration of anatomy into clinical practice with SVPs.
- Hospital settings provide hands-on experience: Students emphasized real patient interactions as indispensable for building clinical confidence.
- Comparable confidence levels: Both modalities were equally effective in fostering student confidence.
- Technical challenges with SVPs: A minority of students faced difficulties with connectivity and navigation.

DISCUSSION

This study compared the effectiveness of SVPs and traditional hospital-based CS for ECE in anatomy. Simulated virtual patients significantly improved student engagement, knowledge retention, and the ability to correlate anatomical knowledge with clinical scenarios, while confidence levels were comparable across groups. These findings suggest that SVPs and CS contribute differently but complementarily to learning outcomes.

Higher engagement in the SVP group likely reflects the pedagogical affordances of interactive, case-based digital platforms. Virtual patient systems structure clinical encounters, embed deliberate practice, and provide immediate feedback that sustains attention and motivation.[5] By contrast, hospital rounds are vulnerable to schedule interruptions, inconsistent case flow, and environmental distractions that dilute learning continuity, particularly for large cohorts.[2] The SVP environment also supported richer visualization of spatial relationships (for example, through 3D reconstructions), which students frequently cited as helpful for grasping complex anatomy.[7]

Knowledge retention gains with SVPs are consistent with evidence that structured, technology-enhanced learning promotes iterative retrieval and application—processes known to consolidate memory.[5] In our context, repeated exposure to standardized cases and integrated quizzes likely reinforced core concepts. The result aligns with early-exposure literature emphasizing that timely, contextualized clinical linkages consolidate basic-science knowledge.[10] Additionally, the capacity of virtual platforms to standardize experiences minimizes the case-to-case variability inherent in hospital teaching, thereby ensuring equitable exposure across learners.[6]

Despite these advantages, confidence did not differ significantly between groups. Prior reports have noted perceived confidence benefits from simulation, but such gains may depend on context, learner level, and task specificity.[3] Our qualitative data suggest complementary mechanisms: SVPs enhanced conceptual clarity and diagnostic reasoning, while real patient contact in CS nurtured interpersonal skills and situational self-assurance. Thus, comparable net confidence may mask distinct, modality-specific strengths.

The superior clinical correlation observed with SVPs likely stems from intentional case design and scaffolding that foregrounds the anatomy–clinical interface. Simulation environments foster hypothesis generation, cue utilization, and iterative decision-making—key ingredients for clinical reasoning.[9] Experimental comparisons further show that virtual patients can match or exceed outcomes achieved with live standardized patients for targeted competencies.[8] Together, these findings indicate that SVPs are particularly potent for cultivating analytic integration of anatomical knowledge into clinical problem solving.

Our results are congruent with broader syntheses. A scoping review of virtual patients reports benefits across knowledge and reasoning outcomes when scenarios are well designed and aligned with objectives.[4] Likewise, immersive and semi-immersive technologies can deepen engagement and presence, which, when coupled with sound instructional design, support meaningful learning.[12] For anatomy specifically, meta-analytic evidence supports 3D visualization for improving spatial understanding and performance, lending a mechanistic explanation for the observed gains in clinical correlation.[7]

Nevertheless, important caveats temper enthusiasm for exclusive reliance on SVPs. Technical barriers—connectivity, interface friction, and software stability—can disrupt flow and frustrate learners, as echoed in our qualitative feedback and prior evaluations of virtual patient systems.[6,11] More fundamentally, simulation cannot fully reproduce tactile cues, patient affect, and the unpredictability of real encounters—elements critical for professional identity formation and psychomotor skill development.[11] These limitations underscore that SVPs are best deployed as complements, not replacements, for authentic clinical experiences.

Strengths of this study include a comparative design with stratified random sampling, clear inclusion/exclusion criteria, and mixed-methods evaluation combining validated questionnaires, objective assessments, and thematic analysis. The concurrent assessment of engagement, retention, clinical correlation, and confidence provides a multidimensional view of learning. Ethical safeguards and standardized procedures enhanced internal validity.

Limitations should be acknowledged. The single-institution setting may constrain generalizability. Although adequately powered for primary comparisons, the sample size may have limited detection of smaller effects or interactions (e.g., differential benefits by prior exposure). Retention was measured immediately post-intervention; long-term durability remains unknown. Finally, outcomes emphasized cognitive and affective domains; procedural competence and bedside comportment were outside the present scope and merit targeted evaluation.

Educational implications are clear. First, integrating SVPs into preclinical anatomy can measurably improve engagement, retention, and clinical linkage—precisely the outcomes ECE seeks to advance. Second, a hybrid model that sequences SVPs with hospital exposure can harness standardization and feedback from simulation while preserving the authenticity and interpersonal skill development of real patient care. Practically, curricula might deploy SVPs to prime foundational concepts and diagnostic frameworks, followed by structured ward-based encounters to consolidate communication, professionalism, and hands-on skills.

Implementation will require institutional support: Robust infrastructure to ensure reliable access; instructional design expertise to craft high-quality scenarios with explicit anatomy–clinic linkages; and faculty development to facilitate debriefing and integrate simulation with bedside teaching. Assessment strategies should mirror intended outcomes, pairing knowledge and reasoning measures with observed clinical performance where appropriate.

Future research should pursue longitudinal, multicenter studies to test the durability and transfer of SVP-derived gains to CSs, including clerkship performance and patient-related outcomes. Comparative cost-effectiveness analyses are also needed, particularly in resource-constrained environments where investments in simulation must demonstrate value relative to traditional modalities. Finally, research on optimal blending—how to time, dose, and align SVPs with hospital experiences—will inform scalable, evidence-based curriculum design.

In sum, SVPs offer a powerful, standardized, and engaging platform for advancing core ECE goals in anatomy, especially the integration of basic science into clinical reasoning. Yet the formative power of real patients remains indispensable. A thoughtful hybridization of modalities is therefore the most plausible pathway to comprehensive, equitable, and efficient training.

CONCLUSIONS

This study demonstrates that SVPs significantly enhance engagement, knowledge retention, and clinical correlation in anatomy education compared to traditional hospital-based ECE. However, both modalities were equally effective in fostering student confidence, underscoring their complementary roles in medical training. While SVPs offer standardized, interactive, and accessible learning opportunities, authentic patient interaction remains essential for developing professional, interpersonal, and procedural skills. A hybrid educational model that strategically integrates SVPs with hospital-based teaching is recommended to provide comprehensive and balanced training, equipping students with both conceptual clarity and real-world clinical competence.

REFERENCES

1. Frenk J, Chen L, Bhutta ZA, et al. Health professionals for a new century: Transforming education to strengthen health systems in an interdependent world. Lancet 2010;376(9756):1923–1958. DOI: 10.1016/S0140-6736(10)61854-5.
2. Prince KJ, van de Wiel MW, Boshuizen HP, et al. A qualitative analysis of the transition from theory to practice in undergraduate training in a PBL medical school. Adv Health Sci Educ Theory Pract 2005;10(2):105–115. DOI: 10.1023/A:1009873003677.
3. Dev P. Implementing early clinical exposure: The benefits and challenges. Med Educ Dev 2014;4(1):12–19.
4. Aghili H, Zary N, Fors U, et al. Virtual patients in medical education: A scoping review. BMC Med Educ 2020;20(1):1–9. DOI: 10.1186/s12909-020-02311-5.
5. Cook DA, Triola MM. Virtual patients: A critical literature review and proposed next steps. Med Educ 2013;47(4):303–311.
6. Zary N, Johnson G, Boberg J, et al. Development, implementation and pilot evaluation of a web-based virtual patient case simulation environment–Web-SP. BMC Med Educ 2006;6(1):1–10. DOI: 10.1186/1472-6920-6-10.
7. Yammine K, Violato C. A meta-analysis of the educational effectiveness of three-dimensional visualization technologies in teaching anatomy. Anat Sci Educ 2014;7(3):158–169. DOI: 10.1002/ase.1510.
8. Triola MM, Feldman H, Kalet AL, et al. A randomized trial of teaching clinical skills using virtual and live standardized patients. J Gen Intern Med 2006;21(5):424–429. DOI: 10.1111/j.1525-1497.2006.00421.x.
9. Wood DF, Medley MA, Bibb CA, et al. Clinical reasoning and decision-making: Exploring the benefits of simulated patients. Med Teach 2011;33(4):e217–e225.
10. Deolalikar S, Nandi J, Pramod J. Introduction of early clinical exposure to first-year students in physiology. CHRISMED J Health Res 2020;7(1):63–67. DOI: 10.4103/cjhr.cjhr_71_19.
11. Salah N. The value of virtual patients in medical education. Ann Behav Sci Med Educ 2010;16(2):29–31. DOI: 10.1007/BF03355129.
12. Freina L, Ott M. A literature review on immersive virtual reality in education: State of the art and perspectives. ELSE Conf eLearning Softw Educ 2015;1(133):10–17. DOI: 10.12753/2066-026X-15-020.

Radiological Evaluation of Sphenoid Sinus Anatomy and Its Critical Relationships: Implications for Endoscopic Surgery

Garima Sehgal[1], Archana Rani[2], Ajay Verma[3]

Abstract

Introduction: The sphenoid sinus (SS), owing to its deep and central location, poses significant diagnostic and therapeutic challenges, especially during endoscopic sinus surgery. Its close anatomical relationships with vital neurovascular structures such as the optic nerves (ONs) and internal carotid arteries (ICA) necessitate a comprehensive understanding of its variable anatomy and pneumatization patterns. Detailed anatomical knowledge is crucial to minimize iatrogenic injury and ensure surgical safety and efficacy.

Materials and methods: This retrospective cross-sectional imaging study analyzed computed tomograms of 55 patients (29 males and 26 females), aged between 18 and 75 years. The evaluation focused on SS anatomy with particular emphasis on septation patterns, pneumatization types, ON relationships, and other variations, including bony dehiscence and clinoid process pneumatization.

Results: A high prevalence of anatomical variations was noted. Deviated intersinus septa were observed in 35% of cases, with 16.5% terminating on the ON canal. The stellar type of pneumatization was the most common, seen in 62% of patients. Optic nerve relationships demonstrated significant variability: 56.36% were close without indentation, 23.64% indented, 16.36% traversed through the sinus, and 3.64% in close proximity to both ethmoid and SS. Additional findings included bony dehiscence in 23.64%, anterior clinoid process (ACP) pneumatization in 29.1%, and posterior clinoid process (PCP) pneumatization in 7.27%.

Conclusion: The study highlights the considerable variability of SS anatomy and its critical implications for endoscopic sinus surgery. Preoperative CT imaging plays an indispensable role in identifying these variations, which frequently predispose patients to ON injury. A thorough understanding of these anatomical relationships is essential to enhance surgical precision and reduce the risk of complications.

Keywords: Anatomical variation, Computed tomography, Endoscopic sinus surgery, Optic nerve, Pneumatization, Sphenoid sinus.

Journal of Anatomical Sciences (2025): 10.5005/jas-11049-0005

Introduction

The paranasal sinuses consist of four sets of hollow, air-containing chambers positioned around the nasal cavity. Among these, the sphenoid sinuses are considered the most inaccessible due to their deep and central location within the sphenoid bone, posterior to the upper part of the nose. Although these structures exist as small hollow spaces from birth, their major growth through a process called pneumatization takes place mainly during adolescence. These cavities can occasionally extend laterally into the greater and lesser wings, pterygoid plates of the sphenoid bone, or posteriorly into the clivus, demonstrating a wide range of anatomical variability.[1]

The sphenoid sinus (SS) chambers are commonly divided by a thin bone wall, measuring roughly 0.6 mm in thickness, positioned along the central sagittal plane. Further partitioning by one or more accessory septa, often asymmetric, adds to the complexity of the internal architecture. The adult dimensions of the SS average 2 cm in height, 1.8 cm in transverse width, and 2.1 cm in anteroposterior depth. The thickness of its walls is variable, with the anterosuperior wall and the roof (planum sphenoidale) generally being the thinnest, making them crucial areas for surgical considerations.[1]

The anatomical proximity of the SS to vital neurovascular structures, including the optic chiasm, optic nerve (ON), pituitary gland (hypophysis cerebri), the internal carotid arteries (ICA), cavernous sinuses, and the vidian nerve, makes this region a critical interface for various surgical approaches.[2] Thin bony plates, or even an absence of bone due to extensive pneumatization, separate the sinus from these critical structures, rendering them

[1–3]Department of Anatomy, King George's Medical University, Lucknow, Uttar Pradesh, India

Corresponding Author: Garima Sehgal, Department of Anatomy, King George's Medical University, Lucknow, Uttar Pradesh, India, Phone: +91 9044513758, e-mail: garimasehgal@kgmcindia.edu

susceptible to iatrogenic injury during surgical procedures.[2] This intricate relationship of the SS presents a formidable diagnostic and therapeutic challenge in otolaryngology and neurosurgery.

Significant visual loss is one of the most debilitating consequences of complications following SS surgery, which can cause serious morbidity.[2] Key factors influencing the viability and safety of procedures like functional endoscopic sinus surgery and the endoscopic endonasal transsphenoidal approach for treating lesions in the tuberculum sellae and supradiaphragmatic regions are the degree of sphenoid pneumatization and particular anatomical variations.[3]

Accurate preoperative imaging is essential because of the substantial effects that these anatomical variations have on surgical outcomes. Computed tomography (CT) is a precise imaging technique for illustrating the intricate structure of the paranasal

sinuses and is particularly useful for defining anatomical landmarks and displaying increasingly deep structures.[2,4]

The objective of this research is to examine the structural characteristics of the SS and establish the frequency of different anatomical variants. By providing a detailed understanding of these configurations, this work intends to serve as a practical guide for neurosurgeons, facilitating improved surgical planning, enhancing safety, and ultimately minimizing operative complications in this delicate anatomical region.

MATERIALS AND METHODS

Study Design and Patient Selection

This research employed a cross-sectional imaging approach through the retrospective examination of tomographic data from patients who received CT examination of the head and neck, at the Department of Radiodiagnosis, King George's Medical University, over a 9-month period. Exclusion criteria were strictly adhered to in order to maintain the integrity of anatomical observations. The study excluded participants who were younger than eighteen, had a history of facial trauma, sinonasal tumors, or had undergone sinus surgery. The total number of participants was 55, with 26 women and 29 men, ages ranging from 18 to 75.

Computed Tomography Protocol and Image Analysis

A 128-slice CT scanner was utilized to conduct all CT examinations. The acquired data were processed using dedicated computer software. DICOM images were reviewed on a workstation, allowing for manipulation of window levels and widths to optimize visualization of bony and soft tissue structures. Sphenoid sinuses were meticulously reviewed in axial, sagittal, and coronal planes. A total of 110 sides (from 55 scans) were analyzed for various anatomical features.

Anatomical Parameters Assessed

The study examined multiple important anatomical characteristics of the SS and the structures that surround it.

Sinus Septation

The presence, location (midline vs deviated), and termination of the intersinus septum were recorded. The termination point, with particular attention to its connection with the optic canal and carotid canal, was specifically noted. The presence and number of accessory septa were also assessed. Optimal assessment was achieved through examination of CT scans in both axial and coronal planes.

Sinus Pneumatization

The degree and type of SS pneumatization were observed in the sagittal view and classified based on traditional criteria, which rely on determining where the posterior wall of the sinus is positioned relative to the sella turcica when viewed in the sagittal plane:[5,6]

- Conchal type: A completely ossified region beneath the sella without any air cavity.
- Presellar type: Air cavity not penetrating beyond a vertical plane parallel to the anterior sellar wall.
- Sellar type: Further divided into incomplete (bulging of the sellar floor into the sinus) and complete (formation of a clival recess due to extension till the posterior margin of the clivus).
- Postsellar type: Pneumatization extending beyond the sella.
- Nonpneumatized: Complete absence of an air cavity.

Position and Relationship of ON

The immediate connection between the ON and these sinuses was documented individually for both the left and right sides, employing the classification framework developed by DeLano et al. to categorize the observed pattern types.[7] Although the ONs were examined across all imaging orientations, the categorization process relied specifically on coronal plane observations. Optic nerve dehiscence was determined when coronal bone window imaging revealed an absence of bony protection covering the nerve.

- Type I: The nerve travels in direct proximity to the SS, showing no indentation or interaction with the posterior ethmoid air cell.
- Type II: The nerve runs alongside the SS, creating an indentation in the sinus wall, yet remains separated from the posterior ethmoid air cell.
- Type III: The nerve travels along a pathway within the SS, where a minimum of half the nerve's circumference is surrounded by air.
- Type IV: The nerve pathway runs in direct proximity to the SS and the posterior ethmoid sinus.

Dehiscence of the Bony Wall

The lack of detectable bone thickness between the sinus and the ON pathway was specifically identified and recorded as bony dehiscence.[8]

Extension of Pneumatization into Surrounding Bones

Air-filled spaces were observed within the anterior clinoid process (ACP), posterior clinoid process (PCP), and the lesser wing of the sphenoid bone, distinguishing between unilateral and bilateral involvement. Pneumatization of the pterygoid process was also assessed.

All observations were meticulously documented, and data were compiled for statistical analysis.

## RESULTS

Sinus Septation

Analysis of sinus septation revealed that the intersinus septum was midline in 36 (65%) cases, while it was deviated in 19 (35%) cases. A clinically significant finding was the termination of the septum on the ON canal in 9 (16.4%) cases and the septum on the carotid canal in 17.3%. In 3 (5%) cases, the septum could not be clearly visualized. In addition to the main septum, accessory septae were observed in 8 (15%) of the study subjects (Fig. 1).

Sinus Pneumatization

The SS pneumatization patterns were categorized, reflecting the distribution across the study population. Among the SS pneumatization patterns identified, the Sellar type represented the most frequently encountered variant at 62%, while the presellar type constituted the second most prevalent pattern at 24%. Less frequently observed were the Conchal type (7%) and the postsellar type (5%) type. The Nonpneumatized type was the rarest, noted in only 2% of cases (Table 1 and Fig. 2).

Optic Nerve in relation to SS

The anatomical relationship between the ON and the SS exhibited significant variation. It was analyzed on both sides and compared between genders. Overall, the most common relationship was the
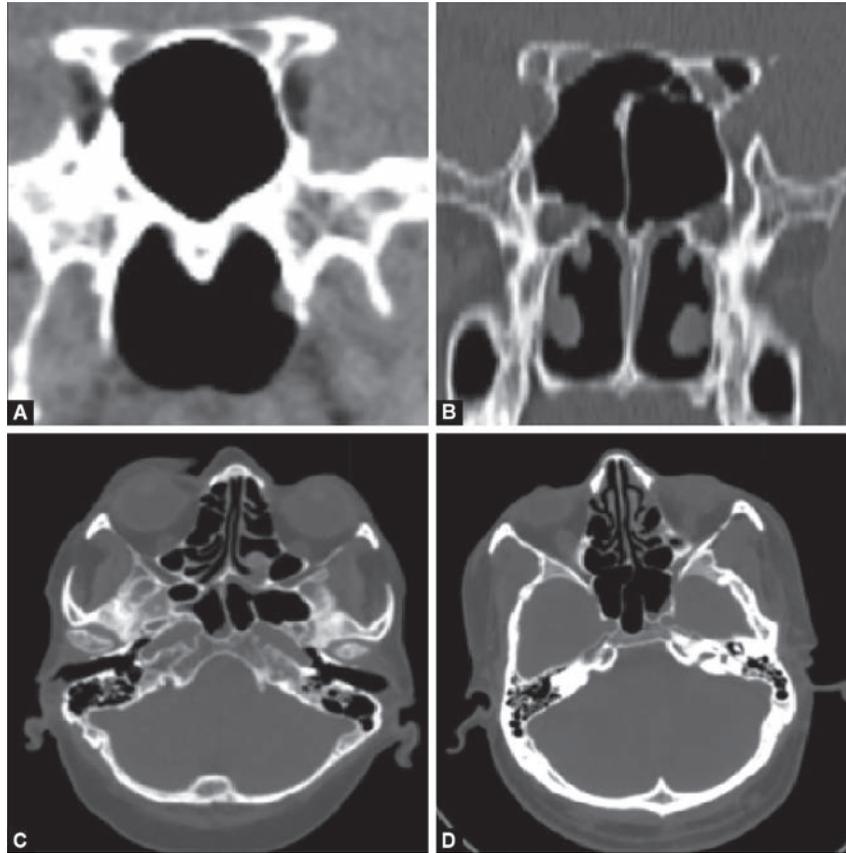
Figs 1A to D: (A) Showing absence of the intersinus septum; (B) Deviation of the septum and termination of septum on optic canal; (C) Accessory septae; (C and D) Termination of intersinus septum on carotid canal

Table 1: Frequency of different types of SS pneumatization

Types of pneumatization	Total
Sellar	62%
Presellar	24%
Postsellar	
Conchal	7%
Nonpneumatized	2%

ON being close to the sinus without indentation, accounting for 62 (56.36%) sides. Indentation of the sinus wall by the ON was seen in 26 (23.64%) sides. In 18 cases (16.36%), the nerve passed through the SS, while in 4 instances (3.64%), it was located near both the ethmoid and SS (Table 2 and Fig. 3).

The findings reveal a statistically meaningful correlation between ON positioning patterns and gender-based differences.

In particular, type III and type IV are more frequent in females, while type I is more frequent in males.

Other Variations

Several other significant anatomical variations were identified:

• Dehiscence of the bony wall: This was present in 23.64% of the cases, indicating an absence of a protective bony barrier between the sinus and adjacent structures (ICA and ON) (Fig. 4A).

• Pneumatization of the ACP: Observed in 29.1% of subjects (Fig. 4B).
• Pneumatization of the PCP: Found in 7.27% of subjects (Fig. 4C).
• Pneumatization of the pterygoid process: Detected in 10.9% of cases (Fig. 4D).

The gender-wise distribution of ACP and PCP pneumatization is detailed in Table 3. In general, ACP pneumatization occurred more frequently among male subjects (52%) compared to female subjects (39%).

No significant differences were observed in pneumatization pattern distribution when comparing male and female subjects.

DISCUSSION

The SS, despite its deep location, is increasingly targeted by endoscopic surgical approaches for a variety of conditions, including pituitary adenomas, cerebrospinal fluid leaks, and other skull base pathologies.[9] The success and safety of these interventions hinge critically on a precise understanding of the highly variable SS anatomy and its intimate relationships with surrounding vital structures.[10] Our study provides valuable insights into the prevalence of these anatomical variations within our study population, reinforcing the need for meticulous preoperative assessment.

Our findings on intersinus septation revealed a midline septum in 65% of cases and a deviated septum in 35%. This contrasts with studies by S Elwany et al.,[11] who reported a midline septum
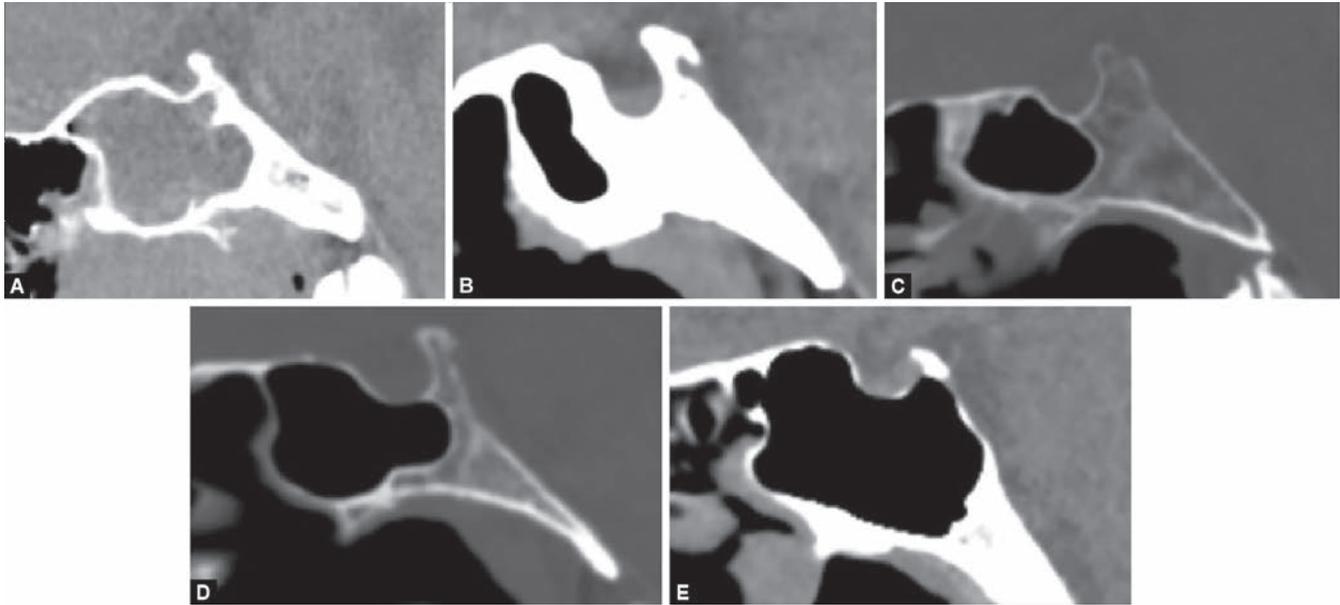
Figs 2A to E: (A) Nonpneumatized; (B) Conchal; (C) Presellar; (D) Sellar; and (E) Postsellar types of sphenoid pneumatization

Table 2: Variable relationship of ON and SS

| Position of ON	Males (n = 58)		Females (n = 52)		Total (n = 110)
	Right	Left	Right	Left	
Type I: Close without indentation	20	18	11	13	62 (56.36%)
Type II: Indented the sinus wall	7	9	5	5	26 (23.64%)
Type III: Traversed through	2	2	9	5	18 (16.36%)
Type IV: Close Proximity to ES and SS	0	0	1	3	4 (3.64%)

p-value = 0.0032

in only 27% and a higher prevalence of deviated septa (73%). DS Sethi et al.[12] observed deviated intersinus septa in 40% of cases, and Renn and Rhoton[13] found it in 32%, figures closer to our observations. The significant prevalence of septal deviation, as observed in our study and others, strongly suggests that the intersinus septum should never be used as a reliable midline guide during hypophysectomy, as this could lead to inadvertent lateral deviation and potential injury to neurovascular structures. The vomer, being a more stable midline structure, is a more accurate guide.[7] Furthermore, the termination of the intersinus septum on the ON canal in 16.4% of our cases and termination on the carotid canal in 17.3% highlights a critical anatomical variant. Sinus septa attachment to the ICA protuberance has been reported as 14.55% by Fernandez et al.[14] The removal of the terminal septum requires utmost care to avoid inadvertent damage to the ON or carotid artery, emphasizing the value of detailed preoperative imaging to identify such risks.

The degree of pneumatization of the sphenoid and its extensions into various components of bone, like greater wings, lesser wings, pterygoid processes, and basi-occiput, varies in different ethnic groups.[3] The extent and characteristics of SS pneumatization play a critical role in determining surgical approaches feasibility and recognizing possible complications. Our study found the sellar type to be the most common (62%), followed by the presellar (24%), conchal (7%), and postsellar (5%) types, with 2% being nonpneumatized. These findings vary compared to some other studies. Elwany S et al.[11] observed 30% presellar and 71% postsellar pneumatization, while Sethi DS et al.[12] reported 27% presellar and 73% postsellar. Sareen D et al.[15] found 25% presellar and 75% postsellar sinuses, and Renn and Rhoton[13] observed 32% presellar and 68% postsellar. In previous literature, the sellar/postsellar type is reported in very high percentages, ranging between 78.5 and 93%.[16–20] Our research identified the conchal type in 7% of the examined cases, which exceeds the frequencies documented in previous literature. No conchal type was detected by Wang et al. and Anusha et al.[20,21] The "postsellar type" is often considered optimal for trans-sphenoid hypophysectomy due to roomy sinuses and thin anterior and floor walls of the sella turcica, whereas the "conchal type" is generally considered a strong contraindication for such surgery due to the lack of an air cavity.[8,22–24]

The development of sphenoid pneumatization is a complex process linked to red-to-yellow marrow conversion within cranial bones. This process, where adipose tissue increases in red marrow, is a prerequisite for pneumatization.[25] Although this occurrence may impact other paranasal sinuses, it shows a stronger association with the SS, which accounts for its significantly higher degree of variation in air-filled spaces. The conversion process in the sphenoid bone typically begins anteriorly (pre-sphenoid) around four months of age and progresses posteriorly towards the clivus, with significant conversion by two years. The reasons for sphenoid predominance in arrested pneumatization are not fully clear, but hypotheses suggest that changes in vasculature and temperature may promote sphenoid marrow conversion.[26]

Understanding the anatomical connections between the ON and the posterior paranasal sinuses plays a vital role in avoiding visual impairments during surgical procedures. DeLano et al.[7] categorized these relationships into four types. On mapping
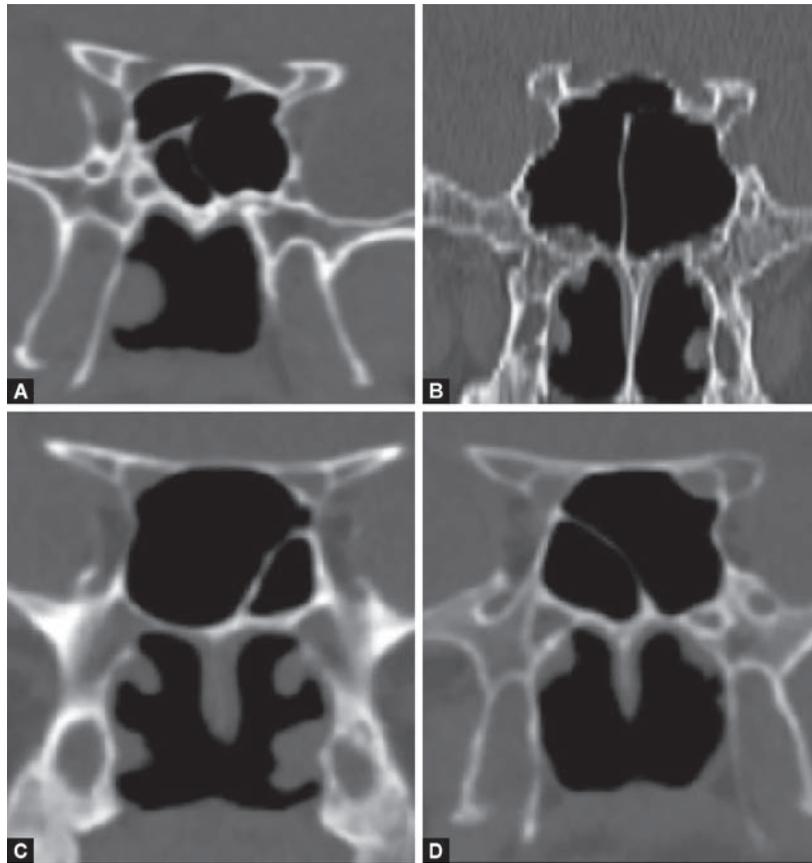
Figs 3A to D: Showing various types of ON relationship; (A) Type I; (B) Type II; (C) Type III (Unilateral, on right side); and (D) Type III (Bilateral)
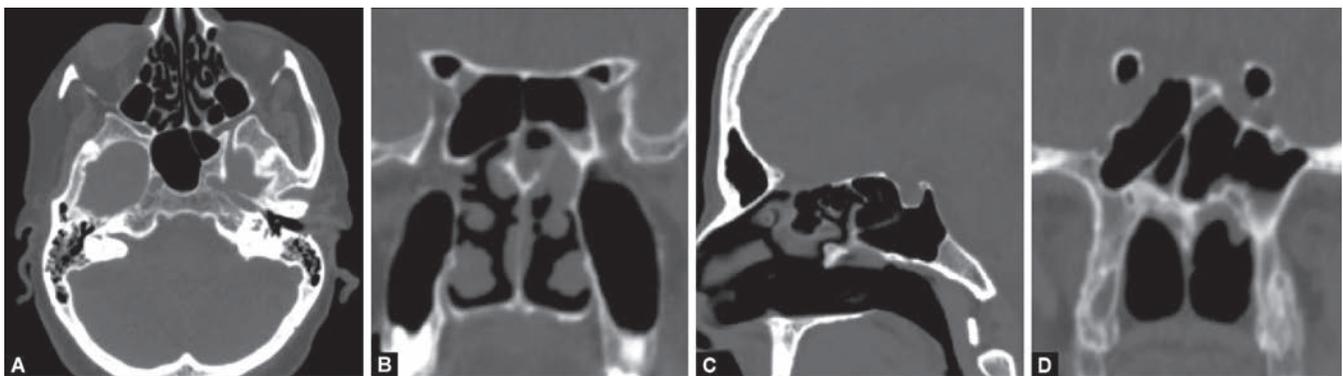
Figs 4A to D: (A) Showing dehiscence of the bony wall between the SS and the right carotid canal; (B) Showing pneumatization of ACP; (C) Showing pneumatization of the PCP; (D) Showing pneumatization of the pterygoid process and the greater wing of the sphenoid

our observations to this classification, the most common sinus relationship was type I (ON close without indentation, 56.36%), followed by type II (indented sinus wall, 23.64%), and type III (nerve traversing through the sinus, 16.36%). Type IV (situated in the immediate anatomical vicinity of the ethmoidal and sphenoidal sinuses) was the least common (3.64%). A study by DeLano et al. reported type I in 76%, type II in 15%, type III in 6%, and type IV in 3% of cases.[7] A study by Kanotra S et al. reported type I position of ON in 69.3%, type II in 20.9%, type III in 3% and type IV in 6.8% of sinuses.[26] Dahal et al. reported type I ON in 65.4% and types II, III, and IV ONs in 16.9, 8.6, and 9.1%, respectively.[27] Comparison of our study with other studies reveals a variable prevalence for type I, type II, type III, and type IV ONs, highlighting the regional differences in anatomical patterns. Trans-sphenoidal surgical procedures carry substantially heightened risks of ON damage when type II anatomical variations are present, with type III configurations posing even more serious concerns for nerve injury. In 23.64% of the examined cases, researchers identified bony dehiscence affecting

Table 3: Gender distribution of sinus pneumatization extension into the anterior and posterior clinoid processes

Gender	ACP Pneumatization			PCP Pneumatization		Total
	Unilateral			Unilateral		
	Right	Left	Bilateral	Right	Left	
Males	10	8	6	4	2	30 (52%)
Females	7	7	5	0	1	20 (39%)
Total	17	15	11	4	3	50 (100%)

($p = 0.534$)

the ON. The thinness or absence of bony coverage over the ON leaves the nerve directly exposed to the surgical field, making precise localization through imaging imperative.[8,17]

The growth and development of sinus cavities face constraints in regions containing vital structures such as blood vessels and nerve pathways, while air-filled spaces can more readily develop in areas lacking these anatomical features. During the progressive pneumatization process, the sinus cavity demonstrates enhanced growth patterns as it develops around adjacent neurovascular components. This developmental process leads to the creation of variable surface irregularities and structural projections from surrounding anatomical elements that extend into the sinus cavity to different degrees. In case of hyper-pneumatization, bony coverings of protruding vessels and nerves may become very thin or even disappear, making these structures dehiscent and more vulnerable to iatrogenic trauma during surgery.[28] The presence of bony dehiscence over vital structures like the ON and ICA is a well-recognized risk factor for iatrogenic injury.[2] Bony dehiscence of the SS overlying the ON has only been found in 4% of cadavers.[29]

Pneumatization was observed in the ACP (29.1%), PCP (7.27%), and pterygoid process (10.9%). Although less frequently discussed, these also represent an extension of the SS air cells. When these processes are pneumatized, the bone forming their walls can be exceedingly thin, potentially creating a direct pathway to the ON (in the case of ACP pneumatization) or other critical neurovascular structures if not recognized prior to surgical manipulation.[18]

These findings collectively emphasize that all anatomical variations, not just those directly involving the ON, contribute to the overall surgical risk profile of the SS region.

CONCLUSION

The SS is a region of considerable anatomical variability. Differences in the septation, pneumatization, and how the sinus relates to the ON occur commonly. The cumulative findings from our study, consistent with the broader literature, strongly advocate for comprehensive preoperative CT imaging with axial and coronal views as a mandatory step before any surgical intervention involving the SS. This imaging technique enables accurate identification of septal arrangements, pneumatization, the complex anatomical relationship between the ON and ICA relative to sinus walls, and the occurrence of bony dehiscence or extended pneumatization extending into neighboring anatomical structures. This detailed anatomical roadmap will enable the surgeons to adjust the trajectory and extent of dissection based on individual variations, to anticipate areas of high risk, and plan strategies to mitigate and enhance patient safety by minimizing the likelihood of iatrogenic injuries.

REFERENCES

1. Shah RK, Dhingra JK, Carter BL, et al. Paranasal sinus development: A radiographic study. Laryngoscope 2003;113(2):205–209. DOI: 10.1097/00005537-200302000-00002.
2. Scuderi AJ, Harnsberger HR, Boyer RS. Pneumatization of the paranasal sinuses: Normal features of importance to the accurate interpretation of CT scans and MR images. AJR Am J Roentgenol 1993;160(5):1101–1104. DOI: 10.2214/ajr.160.5.8470585.
3. Hirenath SB, Gautam AA, Sheeja K, et al. Assessment in variations in sphenoid sinus pneumatization in Indian population: A multidetector computed tomography study. Indian J Radiol Imaging 2018;28(3):273–279. DOI: 10.4103/ijri.IJRI_70_18.
4. Fatterpekar G, Delman B, Som P. Imaging the paranasal sinuses: Where we are and where we are going. Anat Rec (Hoboken) 2008;291(11):1564–1572. DOI: 10.1002/ar.20773.
5. Famurewa OC, Ibitoye BO, Ameye SA, et al. Sphenoid sinus pneumatization, septation, and the internal carotid artery: A computed tomography study. Niger Med J 2018;59(1):7–13. DOI: 10.4103/nmj.NMJ_138_18.
6. Güldner C, Pistorius SM, Diogo I, et al. Analysis of pneumatization and neurovascular structures of the sphenoid sinus using cone-beam tomography. Acta Radiol 2012;53(2):214–219. DOI: 10.1258/ar.2011.110381.
7. DeLano MC, Fun FY, Zinreich SJ. Relationship of the optic nerve to the posterior paranasal sinuses: A CT anatomic study. AJNR Am J Neuroradiol 1996;17(4):669–675. PMID: 8730186.
8. Asal N, Muluk N, Inal M, et al. Carotid canal and optic canal at sphenoid sinus. Neurosurg Rev 2019;42(2):519–529. DOI: 10.1007/s10143-018-0995-4.
9. Alonso RC, de la Peña MJ, Caicoya AG, et al. Spontaneous skull base meningoencephaloceles and cerebrospinal fluid fistulas. Radiographics 2013;33(2):553–570. DOI: 10.1148/rg.332125028.
10. Cappabianca P, Cavallo LM, Colao A, et al. Endoscopic endonasal transsphenoidal approach: Outcome analysis of 100 consecutive procedures. Minim Invasive Neurosurg 2002;45(4):193–200. DOI: 10.1055/s-2002-36197.
11. Elwany S, Elsaeid I, Thabet H. Endoscopic anatomy of the sphenoid sinus. J Laryngol Otol 1999;113(2):122–126. DOI: 10.1017/s0022215100143361.
12. Sethi DS, Stanley RE, Pillay PK. Endoscopic anatomy of the sphenoid sinus and sella turcica. J Laryngol Otol 1995;109(10):951–955. DOI: 10.1017/s0022215100131743.
13. Renn WH, Rhoton AL Jr. Microsurgical anatomy of the sellar region. J Neurosurg 1975;43(3):288–298. DOI: 10.3171/jns.1975.43.3.0288.
14. Fernandez-Miranda JC, Prevedello DM, Madhok R, et al. Sphenoid septations and their relationship with internal carotid arteries: Anatomical and radiological study. Laryngoscope 2009;119(10):1893–1896. DOI: 10.1002/lary.20623.
15. Sareen D, Agarwal AK, Kaul JM, et al. Study of sphenoid sinus anatomy in relation to endoscopic surgery. Int J Morphol 2005;23(3):261–266. DOI: 10.4067/S0717-95022005000300012.
16. Anusha B, Baharudin A, Philip R, et al. Anatomical variants of surgically important landmarks in the sphenoid sinus: A radiologic study in Southeast Asian patients. Surg Radiol Anat 2015;37(10):1183–1190. DOI: 10.1007/s00276-015-1494-8.
17. Akgül MH, Muluk NB, Burulday V, et al. Is there a relationship between sphenoid sinus types, septation and symmetry, and septal deviation? Eur Arch Otorhinolaryngol 2016;273(12):4321–4328. DOI: 10.1007/s00405-016-4138-7.
18. Orhan I, Ormeci T, Bozkurt N, et al. Morphometric analysis of sphenoid sinus in patients with nasal septum deviation. J Craniofac Surg 2019;30(5):1605–1608. DOI: 10.1097/SCS.0000000000005443.
19. El Kammash TH, Enaba MM, Awadall AM. Variability in sphenoid sinus pneumatization and its impact upon reduction of complications

following sellar region surgeries. Egypt J Radiol Nucl Med 2014;45(3):705–714. DOI: 10.1016/j.ejrnm.2014.04.020.

20. Wang J, Bidari S, Inoue K, et al. Extensions of the sphenoid sinus: A new classification. Neurosurgery 2010;66(4):797–816. DOI: 10.1227/01.NEU.0000367619.24800.B1.

21. Anusha B, Baharudin A, Philip R, et al. Anatomical variations of the sphenoid sinus and its adjacent structures: A review of existing literature. Surg Radiol Anat 2014;36(5):419–427. DOI: 10.1007/s00276-013-1214-1.

22. Massoud AF, Powell M, Williams RA, et al. Trans-sphenoidal surgery for pituitary tumors. Arch Dis Child 1997;76(5):398–404. DOI: 10.1136/adc.76.5.398.

23. Fatemi N, Dusick JR, de Paiva Neto MA, et al. The endonasal microscopic approach for pituitary adenomas and other parasellar tumors: A 10-year experience. Neurosurgery 2008;63(4):244–256. DOI: 10.1227/01.NEU.0000327025.03975.BA.

24. Szolar DH, Preidler KW, Ranner G, et al. Magnetic resonance assessment of age-related development of the sphenoid sinus. Br J Radiol 1994;67(797):431–435. DOI: 10.1259/0007-1285-67-797-431.

25. Park SH, Hwang JH. Arrested pneumatization of the sphenoid sinus in the skull base. Brain Tumor Res Treat 2021;9(1):40–43. DOI: 10.14791/btrt.2021.9.e2.

26. Kanotra S, Bashir S, Sharma P, et al. Anatomical variations of the optic nerve in the sphenoid sinus: Do ethnic variations matter? Indian J Otolaryngol Head Neck Surg 2023;75(3):1943–1949. DOI: 10.1007/s12070-023-03798-y.

27. Dahal PM, Parajuli S, Pradhan PM, et al. Evaluation of variations of optic nerve course in relation to posterior paranasal sinuses in MDCT in a tertiary care center of Nepal: A retrospective cross-sectional study. Ann Med Surg (Lond) 2024;86(3):1309–1314. DOI: 10.1097/MS9.0000000000001697.

28. Rahmati A, Ghafari R, AnjomShoa M. Normal variations of sphenoid sinus and the adjacent structures detected in cone beam computed tomography. J Dent Shiraz Univ Med Sci 2016;17(1):32–37. PMID: 26966706.

29. Le CP, Valenzuela AA, Rosenberg M, et al. Sphenoid sinus dehiscence as a risk for visual consequences in an immunocompromised patient. J La State Med Soc 2014;166(2):70–72. PMID: 25075599.

Morphometric Analysis of the Foramen Magnum in 3D Computed Tomography for Sex Determination

Yashika Sharma[1], Arjun Kumar[2], Kuldeep Singh[3]

ABSTRACT

Introduction: The foramen magnum (FM), located at the cranial base, serves as a crucial anatomical passage connecting the brain to the spinal cord. It serves as a passage for critical structures such as the medulla oblongata, surrounding meninges, vertebral arteries, and the 11th cranial nerve (accessory nerve). This study aimed to assess sexual dimorphism in FM dimensions using 3D computed tomography (CT).

Materials and methods: Computed tomography head scans were obtained from Santosh Medical Hospital, Ghaziabad, and Dr OP Gupta Imaging Centre, Meerut. Measurement of the anteroposterior (AP) and transverse diameter (TD) of the FM was done using 3D reconstructed images. The foramen magnum index (FMI) was computed using these values.

Results: Statistically significant sex-based differences were observed in FM dimensions. The mean AP diameter was 35.12 mm in males and 32.17 mm in females. The mean TD was 28.55 mm in males and 26.60 mm in females ($p < 0.000$). The oval shape was most frequently observed, followed by tetragonal and egg-shaped configurations.

Conclusion: Marked sexual dimorphism exists in FM measurements. These parameters have important implications for both neurosurgical planning and forensic identification, especially in cases involving fragmented or incomplete skulls.

Keywords: Anteroposterior diameter, Computed tomography imaging, Foramen magnum, Sexual dimorphism, Transverse diameter.

Journal of Anatomical Sciences (2025): 10.5005/jas-11049-0001

INTRODUCTION

The foramen magnum (FM) is an essential anatomical structure at the posterior cranial base that connects the cranial cavity of the skull with the vertebral canal. Key anatomical components such as the medulla oblongata, meninges, vertebral arteries, and spinal accessory nerve pass through it. Additionally, the basiocciput serves as the attachment site for the apical ligament of the dens and the tectorial membrane, which pass through the FM. The occipital condyles, partially overlapping their anterior margin, articulate with the superior articular surfaces of the atlas vertebra.[1]

Due to its deep location and surrounding soft tissues, clinical evaluation of the FM is often difficult. However, advanced CT imaging facilitates accurate identification of anatomical details compared to assessments on dry skulls.[2,3]

The FM's relative structural resilience makes it particularly useful in forensic assessments, even when other parts of the skull are damaged. Numerous studies have explored its morphometric parameters and confirmed its utility in sex estimation.[4–7] Located within the robust occipital bone and relatively protected, the FM's shape and dimensions can reflect population-specific variations influenced by genetics and environmental factors. Several Indian studies have reinforced the FM's relevance in forensic identification.[8,9]

MATERIALS AND METHODS

Study Design and Data Collection

This cross-sectional study utilized cranial CT scans sourced from the Department of Radiology at Santosh Medical Hospital, Ghaziabad, and Dr OP Gupta Imaging Centre, Meerut. The scans selected were

[1]Department of Radiology, Santosh Medical College, Ghaziabad, Uttar Pradesh, India

[2,3]Department of Anatomy, Ajay Sangaal Institute of Medical Sciences & Research, Shamli, Uttar Pradesh, India

Corresponding Author: Kuldeep Singh, Department of Anatomy, Ajay Sangaal Institute of Medical Sciences & Research, Shamli, Uttar Pradesh, India, Phone: +91 9149088972, e-mail: dr_kuldeep68@yahoo.com

noncontrast axial head CT images showing an intact FM suitable for analysis.

Morphometric Parameters

Two primary measurements were obtained using 3D reconstructed CT images:

- Anteroposterior diameter (APD): Distance from the basion to the opisthion.
- Transverse diameter (TD): Maximum width between the lateral margins of the FM.

Both diameters were recorded in centimeters and used to calculate the Foramen Magnum Index (FMI) using the following formula:

$$= \frac{\text{Transverse diameter}}{\text{Anteroposterior diameter}} \times 100$$

Table 1: Comparative morphometric data between CT images of the FM of males and females

Parameter	Sex	Median (**Mean)	IQR (^SD)	p-value
Age#	M	42	22.75	0.798
	F	45	25.25	
AP diameter of foramen magnum*	M	35.12**	2.499^	0.000
	F	32.17**	2.466^	
Transverse diameter of foramen magnum#	M	28.55	3.00	0.000
	F	26.60	3.05	

*t-test was used. #Mann–Whitney *U* test; ^Indicates that a value is raised to a power

Table 2: CT image-based occurrence of FM shapes in CT images

Parameter	Category	N	%
Sex	F	110	50.0
	M	110	50.0
Shape	Egg shape	23	10.5
	Hexagonal	9	4.1
	Irregular	7	3.2
	Oval	102	46.4
	Pentagonal	17	7.7
	Round	16	7.3
	Tetragonal	46	20.9

Inclusion Criteria

- Computed tomography head scans of patients with a confirmed normal study.
- Participants of various age-groups, genders, and occupational backgrounds.

Exclusion Criteria

- Cases showing any lesions, neoplastic growths, or congenital anomalies involving the FM.
- History of trauma or prior surgery affecting the craniovertebral junction.
- Computed tomography scans of insufficient quality or lacking clear FM margins.

All morphometric assessments were performed using standardized imaging software to minimize observer bias.

Results

The morphometric analysis of the FM from CT scans revealed notable differences in dimensions between male and female subjects. The measurements and statistical comparisons are presented in Table 1.

Males presented with significantly more anteroposterior (AP) and transverse diameters (TDs) as compared to females ($p < 0.000$). The mean AP diameter measured 35.12 ± 2.49 mm in males and 32.17 ± 2.46 mm in females. Similarly, the mean TD was 28.55 ± 3.00 mm for males and 26.60 ± 3.05 mm for females. These results suggest a clear pattern of sexual dimorphism in FM dimensions.

The FM shapes were categorized based on visual assessment of CT images, and their distribution is summarized in Table 2. Among the observed morphologies, the oval shape was most prevalent (46.4%), followed by tetragonal (20.9%) and egg-shaped (10.5%).

Fig. 1: Male AP and TD of FM
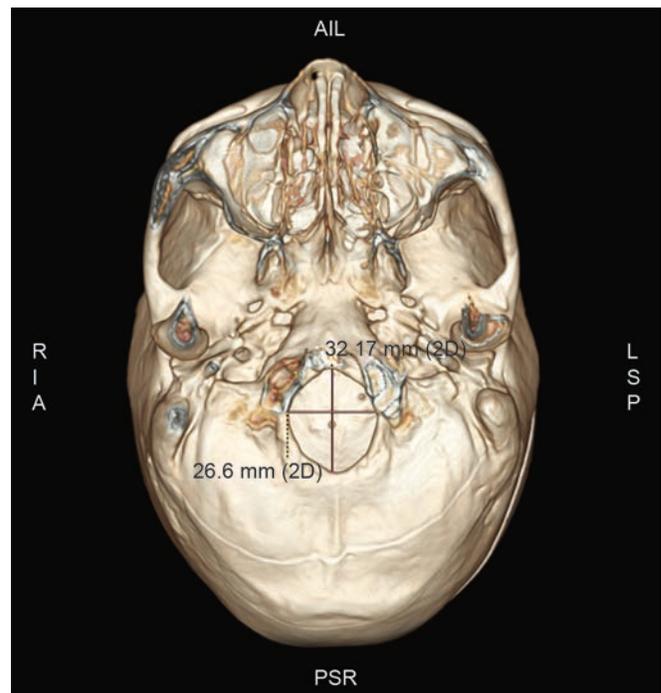
Fig. 2: Female AP and TD of FM

Less frequent variants included pentagonal (7.7%), round (7.3%), hexagonal (4.1%), and irregular (3.2%) forms (Figs 1 and 2).

Overall, the data highlights that there is a difference in linear dimensions and shape distribution of the FM between sexes. These morphometric parameters provide measurable traits that can be utilized for sex estimation in forensic investigations and anatomical studies.

DISCUSSION

The FM, located at the skull base, plays a pivotal anatomical role as it connects the vertebral canal to the cranial cavity. Its structural configuration accommodates critical neurovascular elements and, importantly, exhibits measurable differences between sexes, making it relevant for both clinical and forensic applications.

In the current study, FM dimensions—AP and TD—were assessed using 3D CT imaging. The findings revealed a statistically significant variation between male and female subjects, with male subjects showing consistently greater values for both parameters. Specifically, the mean AP diameter was 35.12 mm in males and 32.17 mm in females, while the mean TD was 28.55 mm in males vs 26.60 mm in females ($p < 0.000$).

These results align with findings reported in previous studies across diverse populations. For example, Manoel et al. observed similar sexual dimorphism in Brazilian skulls, reporting higher average AP and TD values in males.[2] A comparable pattern was documented by Shepur et al. in a study of Nigerian specimens, further validating the reliability of FM dimensions in sex differentiation.[3]

The use of 3D CT imaging in this research offers enhanced accuracy and reproducibility. Unlike assessments of dry skulls, CT scans minimize inter-observer variation and allow application in living individuals, particularly for preoperative evaluations involving the craniovertebral junction. These advantages underscore the clinical significance of the findings, particularly in planning neurosurgical procedures where precise morphometric knowledge is critical.

In terms of shape distribution, the oval type was most common in this study (46.4%), followed by tetragonal and egg-shaped configurations. This differs from some reports—for instance, Paudel et al. found the round shape to be more prevalent in a Nepalese cohort.[10] Such discrepancies may be attributed to genetic and environmental diversity across populations. However, the use of FM shape alone for sex estimation remains limited due to overlap and subjectivity in classification.[6]

Similar trends have been documented in other population-specific research. Atreya and Shrestha, in a Nepalese 3D CT study, and Celik and Akman, in a Turkish cohort, both reported significantly larger FM dimensions in males.[11,12] Despite differences in absolute values, the consistent observation of sexual dimorphism across populations suggests a strong biological basis for these variations.

Nonetheless, it is essential to recognize that while FM dimensions exhibit sex-based differences, overlaps exist. This limits their standalone diagnostic value. Hence, FM metrics should be used in combination with other cranial and postcranial features to enhance accuracy in forensic identification. For instance, pairing FM measurements with data from occipital condyles and basioccipital bones may yield more reliable outcomes.[8]

The need for population-specific reference data cannot be overstated. Morphometric traits are influenced by evolutionary, nutritional, and cultural factors. Therefore, databases tailored to specific regions—like this North Indian cohort—are essential for effective forensic and anthropological application. Relying solely on generalized datasets may lead to misclassification in highly diverse populations like that of India.[4]

Beyond forensic applications, the clinical importance of FM morphometry lies in its relevance to surgeries involving the posterior cranial fossa. A detailed understanding of sex-based anatomical differences can aid in minimizing complications during neurosurgical procedures such as Chiari malformation decompression or tumor excision. The availability of 3D CT reconstructions enhances preoperative planning and surgical precision.

In summary, this study reaffirms the value of FM measurements—particularly the TD—as a reliable supplementary tool for sex estimation. While the AP diameter also shows dimorphism, its overlapping range limits discriminatory power. Foramen magnum shape provides ancillary information but should be interpreted cautiously. These findings have significant utility in forensic analysis, surgical planning, and anatomical research, especially when integrated into region-specific reference models.

CONCLUSION

This study highlights clear evidence of sexual dimorphism in the measurements of the FM, with males exhibiting greater AP and TDs compared to females. Among the two measurements, the TD proved to be more reliable for distinguishing sex. Additionally, the oval shape emerged as the most frequently observed morphological variant.

Morphometric evaluation of the FM using 3D CT imaging offers a practical, noninvasive method for contributing to sex estimation, particularly in scenarios involving incomplete or fragmented skulls. These measurements not only support forensic identification but are also valuable in clinical contexts, especially during preoperative assessment of craniovertebral junction procedures.

Incorporating FM analysis as an adjunct parameter in both diagnostic and medicolegal frameworks can enhance the accuracy and reliability of anatomical profiling.

REFERENCES

1. Standring S, editor. Gray's anatomy: The anatomical basis of clinical practice. 39th ed. London: Elsevier Churchill Livingstone; 2005. p. 460.
2. Manoel C, Prado FB, Caria PHF, et al. Morphometric analysis of the foramen magnum in Brazilian skulls: Its relation to gender. Braz J Morphol Sci 2009;26(2):104–108.
3. Shepur MP, Magi M, Nanjundappa B, et al. Morphometric analysis of foramen magnum. Int J Anat Res 2014;2(1):249–255. Available from: www.ijmhr.org/ijar.htm.
4. Kanodia G, Parihar V, Yadav YR, et al. Morphometric analysis of posterior fossa and foramen magnum. J Neurosci Rural Pract 2012;3(3):261–266. DOI: 10.4103/0976-3147.102602.
5. Kanchan T, Gupta A, Krishan K. Craniometric analysis of foramen magnum for estimation of sex. Int J Med Health Biomed Pharm Eng 2013;7(7):111–113.
6. Suazo GI, Russo PP, Zavando MDA, et al. Sexual dimorphism in the foramen magnum dimensions. Int J Morphol 2009;27(1):21–23. DOI: 10.4067/S0717-95022009000100003.
7. Edwards K, Viner MD, Schweitzer W, et al. Sex determination from the foramen magnum. J Forensic Radiol Imaging 2013;1(4):186–192. DOI: 10.1016/j.jofri.2013.06.004.
8. Holland TD. Sex determination of fragmentary crania by analysis of cranial base. Am J Phys Anthropol 1986;70(2):203–208. DOI: 10.1002/ajpa.1330700207.
9. Kumar NP, Priyanka EN. Morphometric analysis of foramen magnum using helical computed tomography for gender determination. World J Adv Res Rev 2020;8(3):439–444. DOI: 10.30574/wjarr.2020.8.3.0439.
10. Paudel S, Yadav DL, Kayastha P, et al. Measurement of foramen magnum dimensions in computed tomography of head. Nepal J Med Sci 2023;8(1):15–19. DOI: 10.3126/njms.v8i1.50908.

11. Atreya A, Shrestha R. Morphometric analysis of the foramen magnum in sex estimation: A 3D CT study from Nepal on a larger sample. Health Sci Rep 2022;5(6):e999. PMID: 36544619.

12. Celik NG, Akman B. Anatomical analysis of foramen magnum: A 3D slicer CT study. Med Records 2023;5(Suppl 1):182–186. DOI: 10.1002/hsr2.999.

Anatomical Variations of Coronary Arteries: Clinical Implications, Imaging Advances, and Management Strategies

Rizwana Farhat[1], Mudassar Imam[2]

Abstract

Anatomical variations of the coronary arteries, though often under-recognized, hold critical implications for the diagnosis, management, and prognosis of cardiovascular conditions. This narrative review explores the spectrum of coronary artery anomalies (CAAs), their prevalence, and clinical significance, with a particular emphasis on their role in sudden cardiac events, ischemic heart disease, and procedural complications. Advances in non-invasive imaging modalities—such as computed tomography angiography (CTA), magnetic resonance angiography (MRA), and intravascular ultrasound (IVUS)—have enabled detailed visualization of coronary anatomy, enhancing diagnostic accuracy and preoperative planning. Through illustrative case studies and evidence-based analysis, this review outlines the impact of coronary anatomical variants on interventional procedures like percutaneous coronary intervention (PCI) and coronary artery bypass grafting (CABG). It further highlights emerging technologies, including artificial intelligence, 3D modeling, and genomic insights, which are shaping future strategies in coronary diagnostics and therapeutics. A multidisciplinary, patient-centered approach remains pivotal in optimizing outcomes. The article concludes by identifying key research priorities to advance understanding and clinical management of CAAs.

Keywords: Anatomical variation, Artificial intelligence, Cardiac anatomy, Computed tomography angiography, Coronary artery anomalies, Coronary artery bypass grafting, Intravascular imaging, Percutaneous coronary intervention.

Journal of Anatomical Sciences (2025): 10.5005/jas-11049-0002

Introduction

This review presents a comprehensive overview of anatomical variations in the coronary arteries, highlighting their significance in contemporary cardiology and cardiovascular surgery. Recognizing these variations is essential, as they can profoundly influence clinical decisions in diagnosis, intervention, and surgical planning. For instance, the course and origin of the sinoatrial nodal artery (SANa) may deviate significantly from textbook norms, making pre-procedural anatomical knowledge critical for avoiding iatrogenic complications during cardiac interventions.[1]

Understanding both common and rare coronary variations is vital in the context of ischemic heart disease and congenital anomalies. Studies suggest that coronary artery anomalies (CAAs) account for 0.3–5.6% of cases presenting with acute myocardial infarction, underlining the importance of including such anomalies in differential diagnoses—especially among younger patients and athletes.[2]

This review also explores the evolution of imaging modalities used to assess coronary anatomy. Techniques such as computed tomography angiography (CTA) and magnetic resonance angiography (MRA) have transformed diagnostic capabilities, allowing non-invasive visualization of vascular patterns. These tools enable the identification of anomalies that were previously detected only intraoperatively or post-mortem.[3]

Further sections of this review examine how CAAs influence the outcomes of interventions like percutaneous coronary intervention (PCI) and coronary artery bypass grafting (CABG). Unique anatomical courses may necessitate customized interventional strategies and carry implications for both procedural success and long-term outcomes.[4]

Additionally, this article outlines emerging imaging technologies and discusses their role in preoperative planning, intraoperative

[1,2]Department of Anatomy, Hamdard Institute of Medical Sciences & Research and Associated HAHC Hospital, New Delhi, India

Corresponding Author: Rizwana Farhat, Department of Anatomy, Hamdard Institute of Medical Sciences & Research and Associated HAHC Hospital, New Delhi, India, Phone: +91 8368034328, e-mail: farhat.riz@gmail.com

guidance, and long-term management. Future directions, including the integration of artificial intelligence (AI) and genetic insights into coronary anomaly diagnostics, are also highlighted.

By synthesizing anatomical, technological, and clinical perspectives, this article aims to provide clinicians and researchers with an updated understanding of coronary artery variations and their broad clinical implications.

Anatomical Variations of Coronary Arteries

The coronary arteries play a pivotal role in supplying blood to the heart muscle, and their anatomical variations can have significant clinical implications. These variations range from aberrant origins and branching patterns to variations in the number of coronary arteries. For instance, the right coronary artery (RCA) may exhibit variations in its origin, course, and termination, directly impacting coronary artery disease (CAD) diagnosis and treatment outcomes. Understanding anatomical variations is critical; as noted, "Understanding the variations in coronary artery anatomy is crucial for effective diagnosis and treatment in cardiology and

cardiac surgery. Variations can impact surgical outcomes and diagnostic accuracy, necessitating a thorough investigation of these anatomical differences."[4]

Coronary artery anomalies are relatively infrequent, occurring in approximately 1–2% of the population. However, their identification is crucial in cases of ischemic symptoms or sudden cardiac events, particularly in younger individuals. Congenital CAAs, while rare, are important differential diagnoses in patients presenting with ischemic symptoms or sudden cardiac death, especially in young athletes. Accurate diagnosis and individualized treatment strategies based on the specific type of anomaly are essential, as stated: "Congenital CAAs, while rare, are important differential diagnoses in patients with ischemic symptoms or sudden cardiac death, especially in young athletes."[5] Consequently, understanding these anomalies allows for a tailored approach to clinical management.

In diagnostic cardiology, imaging techniques have advanced significantly, enhancing the ability to visualize CAAs accurately. Non-invasive modalities such as CTA and MRA have become indispensable tools. A multidisciplinary approach, including advanced imaging, is crucial for optimal patient care in managing complex CADs, particularly those arising from rare congenital anomalies, emphasizing the synergy between technology and clinical practice.[3]

Furthermore, variations in coronary anatomy can influence the success rates of interventional procedures like angioplasty and CABG. The specific approach to these interventions may require adjustments based on individual anatomical contexts to enhance procedural success and minimize complications. The knowledge of the anatomical variations of the RCA is of utmost importance for cardiologists to better understand cardiac disease and accurately plan and execute cardiac interventions, ensuring effective treatment strategies.[1]

Overall, the exploration of anatomical variations of coronary arteries encompasses a complex interplay of clinical significance and necessity for advanced imaging technologies. The continuous evolution of research in this area promises to enhance our understanding and management of CADs, paving the way for improved patient outcomes and care.

Clinical Significance of CAAs

Coronary artery anomalies present a fascinating and clinically significant aspect of cardiovascular medicine. These anomalies can influence patient care pathways and outcomes, particularly given their potential to lead to myocardial ischemia and sudden cardiac events. Unlike common CAD, which is primarily linked to atherosclerosis, CAAs are rare variants that may complicate diagnosis and treatment. The prevalence of these conditions can vary widely, with estimates suggesting that they occur in approximately 1–2% of the population, yet they are particularly notable in younger patients presenting with acute myocardial infarction, where the prevalence can range from 0.3 to 5.6%.[2] This highlights the imperative for clinicians to maintain a high index of suspicion for CAAs during diagnostic evaluations, especially in symptomatic individuals such as young athletes.

Detecting CAAs in these populations often poses unique challenges. Young athletes may present with symptoms such as syncope or chest pain, leading to an urgent need for accurate diagnosis to prevent potentially fatal outcomes. The ability to visualize these anatomical variations has markedly improved thanks to advanced imaging techniques. Non-invasive modalities like CTA have been especially effective, as "Advanced imaging techniques, particularly 64-slice CT angiography, have proven invaluable for detecting anatomical variations, significantly enhancing the accuracy of diagnosing CAAs and supporting safe surgical interventions."[6] These tools allow for detailed insight into coronary anatomy, aiding in distinguishing normal variations from significant pathologies.

The clinical outcomes associated with CAAs can directly impact the success rates of interventional procedures such as angioplasty and CABG. For instance, "Coronary artery dimensions significantly influence the outcomes of interventions, such as coronary artery bypass graft (CABG) and percutaneous coronary intervention (PCI), where smaller artery sizes are often associated with less favorable outcomes in CAD."[7] This relationship underscores the necessity for tailored interventional strategies that consider the unique anatomical context of each patient, ultimately guiding clinical decision-making.

In addition to procedural considerations, understanding CAAs is essential for developing personalized management strategies. Each type of anomaly may demand a different approach to treatment, reinforcing the need for a comprehensive understanding of these variations. The statement, "Understanding these variations can aid in improving the diagnosis and management of CAD, particularly through tailored approaches that consider the unique branching patterns of the coronary arteries,"[4] encapsulates the essence of this individualized approach. Clinicians must strive to synthesize detailed anatomical knowledge with clinical presentation to optimize outcomes for patients with CAAs.

The complexity of CAAs extends beyond therapeutic interventions, influencing broader aspects of patient care. With ongoing advancements in imaging and intervention techniques, healthcare providers are increasingly equipped to address the challenges posed by these conditions. As our understanding of CAAs continues to evolve, it holds the potential to significantly impact the landscape of cardiovascular risk assessment, surgical planning, and ultimately, patient outcomes.

Techniques for Assessing Coronary Artery Anatomy

The assessment of coronary artery anatomy is critical for effective diagnosis and management of various cardiac conditions. Several imaging modalities are employed to achieve this objective, with each technique presenting unique advantages and limitations. Among these, non-invasive imaging methods like CTA and MRA play pivotal roles in enhancing the understanding of coronary artery anatomy, especially in identifying anomalies.

Computed tomography angiography has gained prominence for its high-resolution imaging capabilities. It allows for rapid and detailed visualization of coronary arteries, enabling clinicians to identify not only the presence of CAD but also variations and anomalies in anatomy. As noted, "Emerging imaging technologies such as CCTA offer non-invasive alternatives but come with limitations, particularly in the presence of significant vessel wall calcification."[8] This limitation can complicate the interpretation of results, thereby emphasizing the need for complementary imaging approaches.

In comparison, MRA offers a different set of strengths, primarily in providing functional assessments of cardiac structures alongside anatomical imaging. While CTA often excels in delineating details, MRA is advantageous in evaluating myocardial perfusion and can

be especially useful in patients who cannot tolerate iodinated contrast agents used in CTA. However, the relative diagnostic accuracy of CTA and MRA varies, leading to ongoing debate in the clinical community regarding the preferred method for assessing specific CAAs.

Three-dimensional (3D) reconstructions derived from these imaging techniques facilitate enhanced visualization of complex coronary anatomies. By transforming traditional two-dimensional images into interactive 3D models, clinicians can better appreciate the spatial relationships of coronary vessels, which is crucial when planning interventional procedures. For instance, the ability to visualize anomalies such as codominant coronary artery patterns or patent foramen ovale (PFO) is vital for interventional cardiology. As stated, "Recognition of anatomical variations like codominant coronary artery patterns and anomalies such as PFO is vital for interventional cardiology."[9] Such anatomical insights help mitigate potential complications during procedures.

Real-time imaging techniques, including intravascular ultrasound (IVUS) and optical coherence tomography (OCT), further contribute to improving procedural outcomes during interventions involving coronary arteries. These modalities allow for high-resolution imaging of the arterial wall and lumen, providing real-time feedback that can guide decision-making during stenting or angioplasty procedures. The synergy of these advanced imaging techniques not only enhances diagnostic accuracy but also influences management strategies, allowing for tailored approaches to cardiac care.

Despite the numerous benefits offered by these imaging techniques, limitations persist. Current methods may struggle with differentiating between benign variations and clinically significant anomalies, necessitating further refinement in imaging technologies to address these challenges. Integrating multimodal imaging, which utilizes various imaging techniques concurrently, has shown promise in improving diagnostic accuracy and treatment planning for complex cases. Through continued advancements in coronary artery imaging, there is significant potential to enhance both the diagnosis and management of patients with various anatomical presentations, ultimately improving clinical outcomes.

Case Studies of Rare Coronary Anomalies

The exploration of rare CAAs is critical in understanding their impact on patient outcomes and management strategies within cardiology. These anomalies pose unique diagnostic challenges and necessitate tailored approaches to treatment. For example, a case of a 35-year-old male athlete presented with syncope during training, leading to the diagnosis of an anomalous left coronary artery arising from the right aortic sinus. The clinical presentation prompted advanced imaging studies, highlighting the importance of non-invasive techniques for accurate detection. "Advanced imaging techniques, particularly 64-slice CT angiography, have proven invaluable for detecting anatomical variations, significantly enhancing the accuracy of diagnosing CAAs and supporting safe surgical interventions."[6] The timely identification of such anomalies can be life-saving, especially in athletes who may experience sudden cardiac events due to these undiagnosed conditions.

Another noteworthy case involved a 28-year-old woman noted for persistent angina despite normal coronary angiography. Further investigation revealed a variant coronary anatomy consisting of a codominant pattern, with both right and left coronary arteries supplying significant portions of the myocardium.

This situation illustrates the potential for misunderstanding in standard assessments and the necessity of high suspicion in specific symptomatic populations: "The coexistence of codominant coronary artery patterns, PFO, and an extensive Chiari network is rare and underscores the importance of recognizing these variations during cardiac procedures to prevent complications."[9] The intersection of these anatomical variations can complicate procedural planning, making awareness crucial in clinical practice.

In another case, an elderly patient presented following a myocardial infarction with a previously undiagnosed single coronary artery, leading to widespread myocardium injury due to its inferior perfusion capability. This case delineates how CAAs can significantly impact mortality and morbidity. As noted, "Complex coronary arteries variants and anomalies may affect adversely myocardial perfusion. Diagnosis of these variants and anomalies may help surgeons to operate safely."[6] In this instance, immediate revascularization was necessary, demonstrating how critical the rapid identification of anomalies can influence acute intervention strategies.

The role of imaging techniques in diagnosing CAAs cannot be overstated. Relying on conventional coronary angiography alone may overlook variants that could be crucial for surgical decisions. For instance, another patient with atypical chest pain was found to have an aberrant right subclavian artery that draped over the esophagus, causing compression. The employment of advanced imaging significantly altered the surgical intervention strategy, as it provided vital information about the anatomical relationships. As studies suggest, "The study highlights significant variations in coronary artery anatomy. Understanding these variations is crucial for improving diagnostic accuracy and surgical outcomes in cardiology and cardiovascular surgery."[4]

Long-term follow-up in these cases reveals that patients often require ongoing management strategies tailored to their specific anatomical configurations. Understanding these variations informs both surgical technique adaptations and postoperative care, enhancing outcomes and minimizing risks associated with these congenital anomalies. Through these case studies, it becomes evident that integrating advanced imaging and a high index of suspicion for CAAs can lead to improved clinical management and patient safety in cardiovascular care.

Impact of Anatomical Variations on Interventional Procedures

Anatomical variations of the coronary arteries can profoundly influence the success and safety of interventional procedures such as angioplasty and CABG. The uniqueness of each patient's coronary anatomy necessitates tailored approaches during these interventions to optimize outcomes. For example, specific anatomical variations can significantly influence the technical success rates of angioplasty procedures. Understanding these variations is essential for interventional cardiologists, as variations can dictate the choice of technique, guiding stent placement, and the approach taken during the procedure.

Coronary artery anomalies are relatively uncommon yet critical aspects of cardiac anatomy. They can lead to various complications during CABG, where the relationship between anatomical variations and surgical outcomes becomes evident. It has been noted that "The study highlights significant variations in coronary artery anatomy. Understanding these variations is crucial for improving diagnostic

accuracy and surgical outcomes in cardiology and cardiovascular surgery."[4] For instance, an anomalous coronary artery that arises from an atypical location can complicate access during surgery, increasing the risk of damage to surrounding structures. These complications underscore the importance of preoperative imaging in identifying anomalies before surgical intervention, allowing for better risk stratification and procedural planning.

Advancements in imaging techniques have revolutionized procedural planning by enabling the detailed visualization of coronary anomalies. Techniques such as 64-slice CT angiography have proven invaluable for detecting anatomical variations, enhancing diagnostic accuracy while supporting safe surgical interventions. As stated, "Advanced imaging techniques, particularly 64-slice CT angiography, have proven invaluable for detecting anatomical variations, significantly enhancing the accuracy of diagnosing CAAs and supporting safe surgical interventions."[6] Such technologies allow clinicians to prepare adequately for potential variations, leading to improved outcomes.

Anatomical variations also affect myocardial perfusion during interventional cardiology procedures. If a coronary artery supplying a significant portion of the myocardium has an aberrant course, it can jeopardize the perfusion during angioplasty. Studies show that appropriate recognition of these variations allows better management of myocardial ischemia, especially in patients with critical lesions. Furthermore, the management of patient care post-intervention becomes increasingly complex when dealing with anomalies, as these patients may require specialized follow-up and monitoring.

In light of these facts, it is clear that a profound understanding of coronary artery anatomy, particularly anatomical variations, is critical for optimizing patient care. It is vital for interventional cardiologists and surgical teams to stay updated on the implications of these variations, utilizing advanced imaging and a tailored approach to improve procedural outcomes. As the field of interventional cardiology continues to advance, these considerations will be crucial for enhancing patient safety and effectiveness in treatment strategies.

Emerging Imaging Technologies in Cardiology

The field of cardiology is witnessing remarkable advancements in imaging technologies that are significantly enhancing the diagnosis and management of various cardiovascular conditions, particularly CAAs. Over the past decade, tools such as CTA and MRA have revolutionized how clinicians visualize and assess coronary anatomy. These advanced imaging techniques have markedly improved diagnostic accuracy and enabled the detailed evaluation of coronary artery structures. As a testament to the efficacy of these modalities, it has been noted that "The detailed morphometric analysis of coronary arteries (lengths, thicknesses, distances) was performed and tabulated, contributing valuable insights into the intricate vascular supply of distinct heart regions."[9] This illustrates how innovations in imaging can uncover critical details that impact clinical decision-making.

Computed tomography angiography, in particular, has become a gold standard in non-invasive coronary imaging, providing rapid acquisition of high-resolution images that facilitate the identification of CADs and CAAs. Through the use of advanced technologies, CTA can delineate not just the presence but also variations in coronary artery anatomy, which is crucial for procedural planning. Furthermore, real-time imaging techniques

such as IVUS and OCT have gained prominence in enhancing procedural decision-making during interventions like angioplasty. These modalities allow clinicians to visualize coronary arteries at a microscopic level, providing insights that can lead to safer and more effective treatment strategies.

One notable advantage of these imaging techniques lies in their ability to perform three-dimensional reconstructions of coronary anatomy. Three-dimensional imaging allows for a more comprehensive understanding of complex vascular configurations, thereby aiding in the planning of interventional procedures. A profound understanding of anatomical variations is crucial for effective diagnosis and treatment in cardiology and cardiac surgery, as highlighted by the assertion, "The coexistence of these abnormalities underscores the importance of awareness among healthcare professionals, particularly in interventional cardiology and congenital heart surgery."[9] Such awareness fosters accurate diagnoses and informed decision-making during critical procedures.

However, despite the numerous benefits of these advanced imaging modalities, limitations persist. Current imaging technologies may struggle with differentiating between benign anatomical variations and clinically significant CAAs, posing challenges for clinicians. As outlined, "Understanding anatomical variations of coronary arteries is crucial for effective diagnosis and treatment in cardiology and cardiac surgery. Variations can impact surgical outcomes and diagnostic accuracy, necessitating a thorough investigation of these anatomical differences."[10] Addressing these limitations through integrated multimodal imaging approaches presents an opportunity to further refine diagnostic processes for complex cases.

Emerging imaging technologies hold great promise in transforming patient management strategies in cardiology. Enhanced diagnostics not only facilitate timely interventions but also significantly improve clinical outcomes by allowing for tailored treatment plans that account for individual anatomical variations. As the field continues to evolve, the integration of these advanced imaging modalities into standard care practices will be integral to optimizing cardiovascular health and enhancing patient safety.

Management Strategies for Coronary Anomalies

Management strategies for CAAs necessitate a multifaceted approach that encompasses diagnostic precision, tailored treatment planning, and transparent communication within multidisciplinary teams. The distinct anatomical variations presented by CAAs pose unique challenges that require adaptable strategies to mitigate their clinical implications. Effective management begins with comprehensive evaluation techniques, as understanding the intricate details of coronary artery anatomy plays a pivotal role in guiding intervention decisions. For instance, advanced imaging technologies such as CTA and MRA have been integral to visualizing these anomalies. Notably, it has been established that "The study of anatomical variations in coronary arteries is crucial to improving diagnostic accuracy and surgical outcomes in cardiology and cardiovascular surgery."[4]

The specificity of management strategies hinges on accurately diagnosing the type of anomaly. For instance, smaller coronary artery sizes correlate with unfavorable outcomes during interventions, emphasizing the need to tailor treatment plans accordingly. As highlighted in recent research, "Understanding the relationship between coronary artery dimensions and coronary

artery disease (CAD) treatment outcomes is vital; smaller artery sizes correlate with less favorable results during interventions."[7] Such nuances underscore the necessity of individualized management plans that account for anatomical variations, leading to improved procedural outcomes.

Collaborative efforts from multidisciplinary care teams further enhance management efficacy. These teams, composed of cardiologists, cardiac surgeons, radiologists, and anesthesiologists, allow for a well-rounded approach in handling complex cases. Each member contributes their expertise to strategize the best course of action, especially when considering interventional techniques tailored to the patient's specific anatomy.[11] Through such collaboration, clinical outcomes can be optimized, improving patient safety and reducing complication rates.

Procedural planning necessitates more than just anatomical knowledge; it also requires an understanding of the technical adaptations needed during interventions. Innovative tools such as modified Judkins catheters have been highlighted to navigate the anomalous origins of coronary arteries effectively. It has been noted that "Innovative use of modified Judkins catheters can effectively navigate the anomalous origins of coronary arteries, emphasizing the need for adaptability in interventional strategies."[12] This adaptability is crucial in ensuring the safety and precision of interventions, as procedural success often hinges on how well the surgical team can adjust to unique anatomical presentations.

Long-term management of patients with CAAs must also be prioritized, given the implications of these anomalies on patient care beyond initial treatment. Continuous follow-up is essential, as the risk of ischemic events can persist due to underlying anatomical anomalies. Surveillance strategies should focus on both management outcomes and quality of life improvements, incorporating patient-reported outcomes to gauge recovery and functionality post-intervention.

In summary, an effective management strategy for coronary anomalies demands a comprehensive understanding of individual anatomical variations, a collaborative healthcare approach, and continuous surveillance of patient outcomes. By focusing on these areas, healthcare providers can enhance patient safety and optimize clinical outcomes for those affected by cardiac anomalies.

Future Directions in Coronary Artery Research

The future of coronary artery research promises to be dynamic and transformative, particularly with advancements in imaging technologies and analytical methodologies. Novel imaging technologies, such as ultra-high-resolution computed tomography and advanced magnetic resonance imaging techniques, are being developed to enhance the detection of CAAs. These innovations aim to provide clearer, three-dimensional representations of the coronary tree, allowing for rapid and accurate identification of variations that influence clinical outcomes.[10] Enhanced imaging capabilities could revolutionize how clinicians approach diagnosis, leading to improved rates of detection and preventing misdiagnosis during acute coronary syndromes.

Furthermore, the incorporation of AI and machine learning (ML) into the analysis of coronary anatomy presents exciting opportunities for research. By leveraging vast datasets, AI algorithms can identify patterns and predict individual risk profiles that clinicians may overlook. Current studies demonstrate that AI systems can analyze angiographic images with high precision, significantly improving diagnostic accuracy for conditions like CAD. This

technology could also aid in predicting outcomes for patients with congenital CAAs, emphasizing the potential of AI to reshape standard cardiology practices.

Genetic factors are increasingly recognized in the study of congenital CAAs, suggesting a strong hereditary component. Understanding the genetic underpinnings of these anomalies may guide personalized treatment approaches, thus optimizing patient-specific management strategies. Research efforts focusing on the genetic basis of CAAs can lead to better screening measures and preventive strategies tailored to at-risk populations.[13]

Multidisciplinary approaches to research, which incorporate cardiologists, geneticists, radiologists, and bioinformaticians, will be crucial in fostering improved clinical management of CAAs. Collaboration among these experts facilitates comprehensive patient assessments, refining treatment protocols that cover a range of angles, from genetic predispositions to real-time anatomical imaging. Such integrative approaches may produce a deeper understanding of the implications of variations in coronary anatomy on overall cardiovascular health.

Exploring long-term clinical outcomes for patients undergoing interventional procedures will also be a vital direction for future research. A comprehensive evaluation of data regarding procedural efficacy in those with well-characterized coronary anomalies would provide insights into surgical planning and postoperative care. Studies have indicated that "The rarity of these three anomalies occurring together necessitates documentation. Detailed anatomical descriptions and measurements of the anomalies are valuable for understanding their potential impact on clinical procedures and patient outcomes."[14] Tracking patient-reported outcomes can further enhance future management strategies, illustrating the real-life impact of interventions on quality of life and symptom reduction.

Lastly, research into the development of new biomarkers capable of stratifying risk for patients with CAAs presents an intriguing frontier. Biomarkers that effectively predict adverse outcomes could complement existing clinical assessments, enabling tailored interventions according to individual risk profiles.

The convergence of these innovative avenues in coronary artery research thus offers significant potential to enhance diagnostic accuracy and optimize treatment approaches, ultimately improving patient outcomes across a spectrum of cardiovascular conditions.

CONCLUSION

The exploration of coronary artery anatomical variations and their clinical implications has revealed fundamental insights that emphasize the significance of understanding these variations in enhancing diagnostic accuracy and patient outcomes in cardiology. One overarching theme that has emerged is the necessity for cardiologists and cardiac surgeons to have a comprehensive understanding of these anatomical differences. "Understanding these anatomical variations is crucial for cardiologists and cardiac surgeons to improve diagnostic accuracy and surgical outcomes. The success of interventions such as CABG and PCI is highly influenced by the recognition of these variations." As findings indicate, recognizing CAAs is vital not only for tailored interventional strategies but also for creating effective management protocols that can mitigate risks associated with these anomalies.

Looking to future clinical practice, the imperative for continuous education and training in the domain of CAAs is

evident. Continuing education programs that focus on advanced imaging techniques and the intricacies of these anatomical variations will be indispensable in equipping practitioners with updated knowledge. Furthermore, a multidisciplinary approach, which includes collaboration among cardiologists, surgeons, and radiologists, is crucial in addressing the complexities arising from congenital coronary anomalies. "A multidisciplinary approach, including advanced imaging, is essential for optimal patient care in cases of CAAs."

As research advances, there are clear pathways for future exploration in understanding coronary artery anatomy. Investigating the genetic factors contributing to these anomalies and employing cutting-edge imaging technologies will be pivotal for improving diagnostic and therapeutic strategies. Emphasizing the need for clinicians to prioritize staying informed about evolving understandings of coronary artery variations ensures that patient care remains responsive to individual anatomical contexts. Through collaborative efforts and innovative research, clinicians can improve the management of patients with CAAs, ultimately enhancing outcomes and fostering advancements in cardiovascular health.

REFERENCES

1. Madeira MD, Pinto FF, Pereira PA. Rare origin of the sinoatrial node artery: An anatomic report and a brief review of the literature. Anat Sci Int 2025;100(1):117–122. DOI: 10.1007/s12565-024-00779-1.
2. Veeraraghavan S, Kidambi BR, Naik SK, et al. The missing coronary: A case series of inferior wall myocardial infarction due to coronary anomalies. Cureus 2024;16(7):e68831. DOI: 10.7759/cureus.68831.
3. Zaveri S, Schrem E, Aykent K, et al. Successful percutaneous coronary intervention in a patient with absent right coronary artery ostium: A case report and literature review. Cureus 2024;16(4):e61165. DOI: 10.7759/cureus.61165.
4. Charitha GN, Narayana PSV, Indira T, et al. Study on variations in the branching pattern of coronary arteries in adult human cadavers. Res J Med Sci 2023;17(5):787–791. DOI: 10.36478/makrjms.2023.5.787.791.
5. Alam M, Tasha T, Ghosh AS, et al. Coronary artery anomalies: A short case series and current review. Cureus 2023;15(5):e38732. DOI: 10.7759/cureus.38732.
6. Al Haris NR. Anatomical variations and anomalies of the coronary arteries: 64-slice CT angiographic appearance. Am J Biomed 2016;4(2):33–41. DOI: 10.18081/2333-5106/016-2/33-41.
7. Muneeb M, Nuzhat N, Niazi AK, et al. Assessment of the dimensions of coronary arteries for the manifestation of coronary artery disease. Cureus 2023;15(10):e51491. DOI: 10.7759/cureus.46606.
8. Oktay O. Learning anatomical image representations for cardiac imaging [dissertation]. London: Imperial College London; 2017.
9. Gandy ST, Zimmerle JS, Maldonado S, et al. A triad of intricacies: An exploration of concomitant codominant coronary artery pattern, patent foramen ovale, and Chiari network in a cadaveric study. Cureus 2024;16(3):e58244. DOI: 10.7759/cureus.55434.
10. Yıldırım D, Agiler M, Akpek S, et al. Anatomy and variations of the arterial supply to the sinoatrial node: Imaging with dual-source cardiac multidetector CT angiography. Turk Gogus Kalp Dama 2010;18(3):290–292.
11. Mıhçioglu AM, Paç FA, Koca S, et al. Evaluation of patients with coronary artery anomalies. Turk J Thorac Cardiovasc Surg 2017;25(2):182–187. DOI: 10.5606/tgkdc.dergisi.2017.13608.
12. Malik P. Grossman's cardiac catheterization, angiography, and intervention. Can J Cardiol 2007;23(7):602. PMCID: PMC2650768.
13. Reza AN, Reza AT, Reza AHA, et al. Study on coronary artery dimensions in normal adult Bangladeshis. Sch Acad J Biosci 2023;11(10):354–360. DOI: 10.36347/sajb.2023.v11i10.005.
14. Muthiah R. Treadmill testing: "Episodic ischemia" in a middle-aged woman aged 46 years. Insights Clin Med Case Rep 2022;1(1):1–23.

Ossification of the Sacroiliac Joint: A Case Series

Jolly Agarwal[1], Abhinav Kumar[2], Suchit Kumar[3]

ABSTRACT

The sacroiliac (SI) joint, a key weight-bearing joint of the axial skeleton, is primarily designed for stability, supported by strong intrinsic and extrinsic ligaments. Although ossification of the SI ligaments is rare, it can lead to joint stiffness, pain, and potential neurovascular compression. During routine osteology demonstrations, three dry human pelves were observed with partial ossification of the anterior SI ligament, with additional ossification of the posterior and sacrotuberous ligaments in one case. These findings suggest progressive age-related changes or possible subclinical pathological processes affecting the joint. This case series highlights the anatomical variability and ossification patterns in the SI joint ligaments. Understanding such ossifications is essential for accurate interpretation of radiological imaging and can aid in the early diagnosis of conditions involving restricted SI joint mobility and sacropelvic pain.

Keywords: Ankylosis, Case report, Joint, Ligament, Ossification, Sacroiliac, Sacrotuberous.

Journal of Anatomical Sciences (2025): 10.5005/jas-11049-0003

INTRODUCTION

Sacroiliac (SI) joint is a stress-relieving joint consisting of syndesmotic and synovial parts. In both sexes, fibrous adhesions and gradual obliteration occur in later ages; complete fibrosis or ossification can be found occasionally in old age.[1]

The SI joint, the largest axial joint in the body, with wide variability, encompasses size, shape, and surface contour.[2] It is a diarthrodial joint having two types of articulation, a postero-superior syndesmosis between interosseous surfaces and a synovial joint between auricular surfaces of ilium and sacrum.[3]

The irregular surface of the joint helps in maintaining stability, but slight antero-posterior rotation occurs in the transverse axis of the joint. During pregnancy, ligaments get loose, allowing for greater rotation and may allow alterations in pelvic diameter at birth.[3]

The SI joint, though it allows only limited motion, can experience reduced mobility due to joint fusion (ankylosis) and the hardening of nearby ligaments. These changes may lead to discomfort and inflammation.[4]

When standing upright, the body's weight passes through the sacrum, which may cause it to tilt forward. This forward tilt is resisted by the posterior SI and sacrotuberous ligaments, which function similarly to a self-locking or "screw-home" mechanism that stabilizes the joint. In females, particularly during and after puberty and throughout pregnancy, the SI joint becomes more flexible. This increased laxity reduces the likelihood of ankylosis in women, as the joint prioritizes mobility over structural strength and stability.[4]

Unlike other joints where degeneration usually starts with damage to the hyaline cartilage—leading to cartilage breakdown and exposure of the underlying bone, eventually forming bony fusion—the SI joint tends to follow a different degenerative path. In older adults, it often develops fibrous rather than bony ankylosis. This involves the formation of fibrous tissue bands or fibrocartilage-like structures within the joint space that connect the sacrum and ilium. Such fibrocartilage typically forms in dense connective tissues subjected to mechanical stress, such as where ligaments or tendons anchor into bone.[5]

[1,2]Department of Anatomy, Government Doon Medical College, Dehradun, Uttarakhand, India

[3]Department of Anatomy, Gautam Buddha Chikitsa Mahavidyalaya, Dehradun, Uttarakhand, India

Corresponding Author: Jolly Agarwal, Department of Anatomy, Government Doon Medical College, Dehradun, Uttarakhand, India, Phone: +91 6398682933, e-mail: drjolly21177@gmail.com

How to cite this article: Agarwal J, Kumar A, Kumar S. Ossification of the Sacroiliac Joint: A Case Series. J Anat Sciences 2025;33(1):25–26.

Source of support: Nil

Conflict of interest: None

In ankylosing spondylitis, inflammation of joints occurs mostly in the axial skeleton, leading to reactive fibrosis and eventually joint fusion, associated with immobility and kyphosis, the SI joint being involved most commonly, followed by intervertebral joints.[6]

CASE SERIES

During a routine osteology demonstration for undergraduate medical students in the Department of Anatomy, three dry human pelvises were found to have an ossified SI ligament.
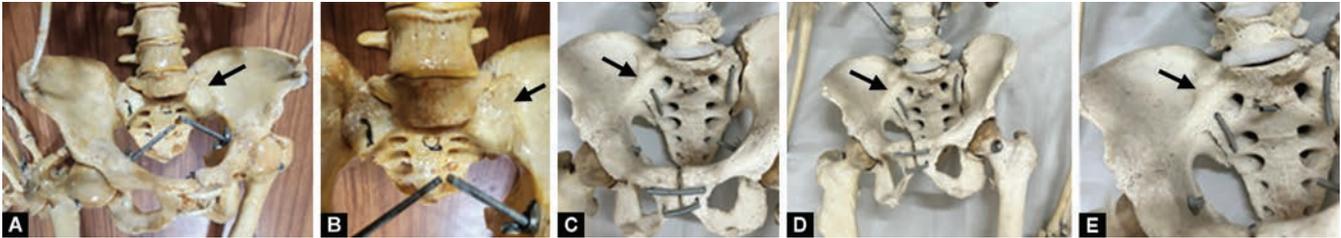
Case Report 1

Partial ossification of the anterior SI ligament of the SI joint on both sides was found. Only the superior part of the anterior SI ligament was ossified on the ventral side. On the dorsal surface, the posterior SI ligament was partially ossified on both sides. The sacrotuberous ligament on both sides was also ossified. Also, osteophytes were seen on the body of the S1 vertebra (Fig. 1).

Case Report 2

Partial ossification of the superior part of the anterior SI ligament was found on the left SI joint only (Figs 2A and B).
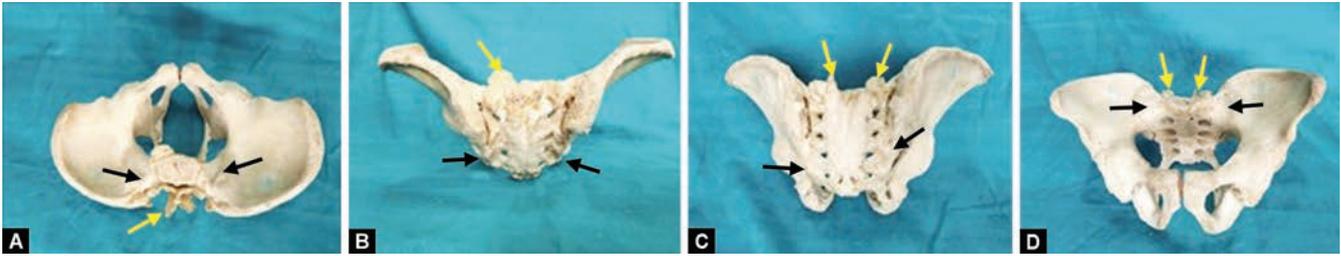
Figs 1A to D: Ossification is marked by black arrows and osteophytes are marked by yellow arrows with ossification of anterior SI ligaments on both sides seen in "A" and "D," ossification of sacrotuberous ligaments on both sides is seen in "B," ossification of posterior SI ligaments on both sides is seen in "C," and osteophytes on body of S1 vertebra is seen in "A to D" (Pelvis 1)

Figs 2A to E: (A and B) Showing ossification of the anterior SI ligament on the left side. (Pelvis 2); (C to E) Showing ossification of the anterior SI ligament on the right side (Pelvis 3)

Case Report 3

Partial ossification of the superior part of the anterior SI ligament was found on the right SI joint only (Figs 2C to E).

Discussion

The SI joint is primarily structured to provide stability, with its main function being the transfer of weight from the upper body to the lower extremities. This stability is maintained by both intrinsic and extrinsic ligamentous structures. The intrinsic ligaments include the anterior SI ligament on the front side, and the posterior and interosseous ligaments on the back. In addition, the sacrotuberous and sacrospinous ligaments serve as key extrinsic stabilizers. Studies examining dry skeletal specimens have indicated that complete fibrous ankylosis is often associated with the presence of microporosity. In cases where microporosity is observed along with a notably thickened subchondral bone layer, it suggests that nearby ligaments may have extended onto the articular surface, transforming a portion of the joint surface into a site of ligament attachment.[5]

Singh R found partial ossification of the anterior SI ligament on the left side only, with no ossification of the posterior SI and interosseous ligament.[4]

Pankaj AK et al. found unilateral ankylosis of the right SI joint with complete ossification of the anterior, posterior, and interosseous SI ligaments of the right SI joint.[3]

Sharmila and Devi found one pelvis with bilateral ankylosis of the SI joint and ossified sacro-spinous ligament, sacrotuberous ligament, and transverse acetabular ligament.[7]

Conclusion

Knowledge of SI joint ankylosis is important as it leads to pain and decreased motility of the joint and may cause neurovascular compression. So, proper anatomical knowledge can help in early diagnosis on radiological studies and treatment of compression syndromes.

References

1. Standring S. Gray's Anatomy E-book: The Anatomical Basis of Clinical Practice. 42nd ed. London: Elsevier Health Sciences; 2021.
2. Cohen SP. Sacroiliac joint pain: A comprehensive review of anatomy, diagnosis and treatment. Anesth Analg 2005;101(5):1440–1453. DOI: 10.1213/01.ANE.0000180831.60169.EA.
3. Pankaj AK, Rani A, Verma RK, et al. Unilateral ankylosis of sacroiliac joint: A case report. [Unpublished manuscript]. n.d.
4. Singh R. Ossification of anterior sacroiliac ligament and its clinical significance. J Morphol Sci 2015;32(4):259–261. DOI: 10.4322/jms.065213.
5. Ikeno H, Matsumura H, Murakami G, et al. Which morphology of dry bone articular surfaces suggests so-called fibrous ankylosis in the elderly human sacroiliac joint? Anat Sci Int 2006;81(1):49–56. DOI: 10.1111/j.1447-073X.2006.00126.x.
6. DonTigny RL. Function and pathomechanics of the sacroiliac joint: A review. Phys Ther 1985;65(1):35–44. DOI: 10.1093/ptj/65.1.35.
7. Sharmila B, Devi SK. Bilateral ankylosis of sacroiliac joint with ossified sacrospinous, sacrotuberous and transverse acetabular ligaments. Int J Anat Var 2011;4:123–127.

Horseshoe Kidney: A Case Report

Fatima Begum[1], Vinay Sharma[2]

Abstract

Horseshoe kidney (HSK) represents the most common congenital anomaly of the urinary tract, occurring in approximately 1 in 400–600 individuals, with a male predominance. It typically results from fusion of the lower poles of the kidneys by a fibrous or parenchymal isthmus and is frequently associated with ectopia, malrotation, and vascular anomalies. Although usually asymptomatic and often discovered incidentally during imaging for unrelated conditions, HSK may predispose individuals to complications such as hydronephrosis, nephrolithiasis, infection, and ureteropelvic junction (UPJ) obstruction. We report the case of a 37-year-old woman who presented with two months of amenorrhea and severe abdominal pain. With a provisional diagnosis of ectopic pregnancy, an ultrasound was performed, but it proved inconclusive. Subsequent magnetic resonance imaging (MRI) revealed an ectopic pregnancy along with the incidental finding of an HSK. The kidneys were normally positioned, fused at their lower poles by a parenchymal band, and showed no associated ureteral abnormality. Morphologically, the anomaly corresponded to the U-shaped type described in the literature. This case highlights the importance of considering renal fusion anomalies in radiological evaluations performed for unrelated indications. Recognition of HSK is clinically significant not only for the diagnosis of associated conditions but also for planning surgical or interventional procedures due to altered anatomy and vascular patterns.

Keywords: Case report, Congenital malformation of urinary system, Horseshoe kidney, Hydronephrosis, Vesicoureteral reflux.

Journal of Anatomical Sciences (2025): 10.5005/jas-11049-0004

Introduction

The urinary system's most prevalent congenital fusion anomaly is horseshoe kidney (HSK), which affects roughly one in every 400–600 people and demonstrates a higher incidence rate among males compared to females at a 2:1 ratio. In anatomical dissections, this abnormality incidence varies from 0.15 to 0.48% in the literature. There is no racial and genetical determination known, although HSK has been reported in monozygotic twins and in siblings within the same family.[1,2]

It commonly presents with a combination of three anatomical anomalies: Renal ectopia, malrotation, and vascular variations. In the majority of cases, the condition involves fusion of the two kidneys at their lower poles through either a fibrous isthmus or a parenchymal band.

The HSK in adults is usually an asymptomatic disorder, and its detection is incidental during intravenous pyelography (IVP), ultrasound, computed tomography (CT) scan, and magnetic resonance imaging (MRI) of the abdomen performed for some other reasons.[3] When clinical manifestations are present, they are usually linked to associated conditions such as hydronephrosis, infections, or nephrolithiasis. The predominant symptom in such cases is severe abdominal pain that radiates to the lower lumbar region.

Even in antenatal diagnosis, an HSK may be made as early as the first trimester of pregnancy by use of high-frequency transvaginal sonography.[4] On the contrary, Lallas et al.[5] stated that HSK is associated with to form of ureteropelvic junction (UPJ) obstruction in approximately one-third of cases. It is a hypothesis that UPJ obstruction develops after congenital stricture, high ureteral insertion, and abnormal ureteral course over the parenchymal band, crossing the vessels supplying the isthmus or abnormal motility of the UPJ segment.[6] Horseshoe kidney, due to the location in the lower part of the abdomen and the presence of the isthmus across the midline, may be associated with a risk of damage by blunt trauma of the abdomen.[7]

[1,2]Department of Anatomy, Muzaffarnagar Medical College, Muzaffarnagar, Uttar Pradesh, India

Corresponding Author: Vinay Sharma, Department of Anatomy, Muzaffarnagar Medical College, Muzaffarnagar, Uttar Pradesh, India, Phone: +91 9837154651, e-mail: vinay_sharma1979@yahoo.com

Case Description

The current case involves a 37-year-old married woman who reported to St. Mary's Polyclinic, Kursi Road, Lucknow, with a history of two months of amenorrhea and severe abdominal pain. With a probable diagnosis of ectopic pregnancy, an ultrasound scanning was done for the same, which was not conclusive. However, MRI revealed that it was a case of ectopic pregnancy with additional findings of an HSK (Fig. 1). The kidneys were normally positioned, joined at their lower poles by a parenchymal band, and demonstrated ureters with a normal appearance.

Discussion

Oktem et al.[8] grouped the HSK on the basis of fusion morphological appearance into two types. That is U and L shaped. The U-shaped HSK develops through the medial fusion of the kidneys positioned symmetrically on either side of the vertebral column. In contrast, the L-shaped type results from lateral fusion between

Fig. 1: Magnetic resonance imaging shows the location of the paravertebral kidney (green arrows) and in midline parenchymal band (red arrow)

one vertically oriented and one horizontally oriented kidney, with the isthmus located lateral to the midline. This type is asymmetrical in shape. The present case falls into the former U-shaped HSK.

Embryogenesis

There are theories regarding about HSK embryogenesis.

- The classic theory of mechanical fusion proposes that at the 4th week of gestation, during the metanephric stage, while the kidneys are still in the pelvis and in close proximity, their lower poles enter into contact and fuse in the midline, as they ascend through the arterial fork formed by the umbilical arteries, the inferior mesenteric artery forming an HSK.[3,9–12]
- It has also been proposed that HSK can result as a teratogenic event that involves the abnormal migration of posterior nephrogenic cells that form a parenchymal isthmus.[3,9–11]

CONCLUSION

Horseshoe kidney carries a significant predisposition to urinary tract infections as described by Natsis et al. in 2005. These infections typically arise from a combination of urinary reflux, stasis, and stone formation, and they represent an important contributor to mortality in affected individuals.[13] These infections typically arise from a combination of urinary reflux, stasis, and stone formation, and they represent an important contributor to mortality in affected individuals. It is found in approximately one-third of patients who have HSK.[9] Ascending infection is the most common type, usually caused by vesicoureteral reflux, which is presented in approximately 50% of HSK patients.[10]

Horseshoe kidney is an unusual anomaly, but its existence and morphological structure are important factors to be considered.

REFERENCES

1. Yoshinaga K, Kodama K, Tanii I. Morphological study of a horseshoe kidney with special reference to the vascular system. Anat Sci Int 2002;77:134–139. DOI: 10.1046/j.0022-7722.2002.00016.x.
2. Gleason PE, Kramer SA. Ectopic kidneys and renal fusion anomalies. AUA Update Ser 1995;33:268–271.
3. Boatman DL, Cornell SH, KÖlln CP. The arterial supply of horseshoe kidneys. Am J Roentgenol Radium Ther Nucl Med 1971;113:447–451. DOI: 10.2214/ajr.113.3.447.
4. Bronstein M, Kushnir O, Ben-Rafael Z. Transvaginal sonographic measurement of fetal kidneys in the first trimester of pregnancy. J Clin Ultrasound 1990;18:299–301. DOI: 10.1002/jcu.1870180413.
5. Lallas CD, Pak RW, Pagnani C, et al. The minimally invasive management of ureteropelvic junction obstruction in horseshoe kidneys. World J Urol 2011;29:91–95. DOI: 10.1007/s00345-010-0523-9.
6. Yohannes P, Smith AD. The endourological management of complications associated with horseshoe kidney. J Urol 2002;168:5–8. PMID: 12050480.
7. Murphy JT, Borman KR, Dawidson I. Renal autotransplantation after horseshoe kidney injury: A case report and literature review. J Trauma 1996;40(5):840–844. DOI: 10.1097/00005373-199605000-00031.
8. Oktem H, Gozil R, Calguner E, et al. Morphometeric study of horseshoe kidney. Med Princ Pract 2008;17:80–83. DOI: 10.1159/000109596.
9. Cascio S, Sweeney B, Granata C. Vesicoureteral reflux and ureteropelvic junction obstruction in children with horseshoe kidney: Treatment and outcome. J Urol 2002;167:2566–2568. PMID: 11992090.
10. O'Brien J, Buckley O, Doody O. Imaging of horseshoe kidneys and their complications. J Med Imaging Radiat Oncol 2008;52:216–226. DOI: 10.1111/j.1440-1673.2008.01950.x.
11. Tijerina GO, Uresti J, Urrutia VE. Anatomical study of the horseshoe kidney. Int J Morphol 2009;27:491–494. DOI: 10.4067/S0717-95022009000200030.
12. Sadler TW. Langman's Medical Embryology, 9th ed. Philadelphia: Lippincott Williams & Wilkins; 2004. p. 321.
13. Natsis K, Piagkou M, Skotsimara A, et al. Horseshoe kidney: A review of anatomy and pathology. Surg Radiol Anat 2014;36(6):517–526. DOI: 10.1007/s00276-013-1229-7.

Anatomical Variation in Gonadal Venous Drainage: A Case Report with Clinical Perspective

Rizwana Farhat[1], Mudassar Imam[2]

Abstract

Gonadal vessels, including testicular and ovarian arteries and veins, exhibit numerous anatomical variations that are crucial for surgeries involving the posterior abdominal wall, renal transplants, and treatment of conditions like varicocele and testicular tumors. These anatomical anomalies can lead to complications such as infertility, hydronephrosis, and varicocele formation. Knowledge of gonadal vessels plays an important role in renal transplant surgeries due to their anatomical variations and proximity to renal structures. Variations in gonadal veins, such as duplication or drainage into accessory renal veins, can influence the choice of a suitable donor kidney. Surgeons must assess these variations to ensure proper vascular connections during transplantation.

Henceforth, understanding the anatomy and variations of gonadal vessels is critical for ensuring successful renal transplant outcomes and avoiding complications during surgery. This clinical case study examines the anatomical differences in how gonadal vessels originate and drain, emphasizing their importance during surgical procedures and their relationship to embryological development.

Keywords: Accessory renal veins, Case report, Gonadal vein, Inferior vena cava, Renal vein.

Journal of Anatomical Sciences (2025): 10.5005/jas-11049-0006

Introduction

The gonadal veins exhibit asymmetric drainage patterns. The right gonadal vessel empties directly into the inferior vena cava (IVC) at a sharp angle, positioned slightly below where the renal veins connect. In contrast, the left gonadal vessel flows into the left renal vein, forming a perpendicular junction.[1] Variations in gonadal vein drainage can complicate surgical procedures and require careful identification to avoid vascular injury. Understanding these relationships is essential for surgeons and radiologists to ensure accurate diagnosis and safe surgical interventions. Surgeons must be aware of these anomalies to avoid iatrogenic injuries and ensure patient safety.[2]

Detailed anatomical knowledge of the gonadal vessels helps surgeons to minimize risks, ensure successful outcomes, and avoid complications during various abdominal and pelvic surgeries. Variations in gonadal vein drainage, such as abnormal drainage patterns, can lead to varicocele formation, which is a known cause of male infertility.[3] Abnormal drainage patterns, such as the right testicular vein draining into the right renal vein, can lead to stasis of urine and hydronephrosis, further complicating patient health.[2] Understanding gonadal vein drainage variations is essential for accurate diagnosis, effective treatment, and prevention of complications during invasive procedures. This study highlights how crucial it is for medical professionals, particularly surgeons and radiologists, to comprehend these anatomical differences in order to prevent procedural complications, with particular attention to their clinical and anatomical relevance.

Case Description

An anatomical variation in the drainage of the right testicular vein was observed during the routine dissection of the cadavers in the Department of Anatomy, Hamdard Institute of Medical

[1,2]Department of Anatomy, Hamdard Institute of Medical Sciences & Research and associated HAHC Hospital, New Delhi, India

Corresponding Author: Rizwana Farhat, Department of Anatomy, Hamdard Institute of Medical Sciences & Research and associated HAHC Hospital, New Delhi, India, Phone: +91 8368034328, e-mail: farhat.riz@gmail.com

Sciences and Research, New Delhi. The dissection was performed according to the guidelines of Cunningham's manual textbook. During anatomical examination of the posterior abdominal wall in an adult male cadaver, researchers found that the right testicular vein emptied into the right renal vein rather than connecting directly to the IVC. The arrangement of structures in the hilum of the kidney was anatomically normal, that is, vein, artery, and pelvis were present antero-posteriorly. No additional accessory renal vessels were identified bilaterally. The left testicular vein was found to empty into the left renal vein on the corresponding side (Fig. 1).

Discussion

The relationship between the gonadal veins and renal veins is anatomically significant and varies between the right and left sides.

Fig. 1: Right testicular vein draining into right renal vein

The right gonadal vein typically drains into the IVC, while the left gonadal vein drains into the left renal vein.[1] Variations in these drainage patterns are rare but clinically significant, especially in invasive interventions.[3] Various studies have been reported the varying incidences of gonadal vein anomalies, highlighting their clinical significance. Duplication of the right testicular vein has been observed in 8.8% of cases by Duques et al.[4] Abnormal drainage of the right testicular vein into the right renal vein has been reported with varying frequencies: 1.33% by Asala et al., 4.16% by Sharmistha et al., 6.6% by Gupta et al., and 10% by Phalgunan et al.[5–8] This case report paralleled previous research findings that documented the right testicular vein connecting to the right renal vein rather than emptying directly into the IVC, as observed in a male cadaveric specimen. In a study conducted on 12 adult cadavers (10 male, 2 female), the research revealed that 8.3% of cases exhibited atypical routing of the right testicular vein, where it connected to the right renal vein instead of following normal drainage patterns. In two instances, this vessel was observed to empty into the right renal vein rather than the IVC, representing an uncommon anatomical variation. This variation can lead to complications such as varicocele, male infertility, and hydronephrosis due to urine stasis.[9] A separate investigation spanning 3 years examined 20 adult cadavers (comprising 12 males and 8 females) and revealed that anatomical variations occurred in 10% of the male specimens, with these variations encompassing the presence of multiple right renal veins as well as instances where the right testicular vein drained directly into the right renal vein. These anomalies are attributed to errors in embryological development and are more common on the right side.[8] Additionally, right ovarian vein variations were noted, with one case showing drainage into the right renal vein and another showing duplication with two veins draining into the IVC at different points.[10] Understanding these variations is crucial for surgeons and clinicians to prevent vascular injury during procedures such as renal transplantation, angioplasty, or vascular reconstruction.

Embryological Basis

The formation of gonadal blood vessels demonstrates a strong connection to the development of the IVC and renal veins. The gonadal veins originate from the posterior portion of the subcardinal vein. The asymmetric termination of gonadal veins is due to the differential development of the supracardinal and subcardinal veins. Variations occur when the anastomosis between these veins deviates from the normal pattern, leading to abnormal drainage routes.[11]

CONCLUSION

Anatomical variations in renal and gonadal veins, though uncommon, have significant implications for surgical and clinical practice. A detailed understanding of gonadal vein variations is crucial for surgeons to prevent iatrogenic injuries, ensure patient safety, and avoid medicolegal issues. These anomalies should be considered in the differential diagnosis of male infertility and varicocele. Continued research and documentation of these variations will enhance surgical outcomes and reduce complications, underscoring the importance of anatomical studies in medical practice.

REFERENCES

1. Gray H. The anatomical basis of clinical practice, 39th edition. Susan Standring, Elsevier Churchill Livingstone; 2005.
2. Singh R, Jaiswal A, Shamal SN, et al. Variation in the origin of the testicular arteries and drainage of the right testicular vein. Int J Morphol 2011;29(2):614–616. DOI: 10.4067/S0717-95022011000200052.
3. Sonje P, Kanasker N, Vatsalaswamy P. Variations in the origin and draining pattern of gonadal vessels with their surgical significance and developmental correlations. Indian J Anat 2020;9(1):39–43. DOI: 10.21088/ija.2320.0022.9120.6.
4. Duques P, Rodrigues JR, Neto FBS, et al. Anatomical study of the left renal vein of human Brazilians cadavers. Medicina Ribeirão Preto 2002;35:184–191. DOI: 10.11606/issn.2176-7262.v35i2p184-191.
5. Asala S, Chaudhary SC, Masumbuko-Kahamba N. Anatomical variations in the human testicular blood vessels. Ann Anat 2001;183(6):545–549. DOI: 10.1016/S0940-9602(01)80064-9.
6. Sharmistha B, Chattopadhyay JC, Panicker H. Variations in renal and testicular veins: A case report. J Anat Soc India 2006;55:69–71.
7. Gupta R, Gupta A, Aggarwal N. Variations of gonadal veins: Embryological perspective and clinical significance. J Clin Diagn Res 2015;9:8–10. DOI: 10.7860/JCDR/2015/9493.5578.
8. Phalgunan V, Mugunthan N, Rani DJ, et al. A study of renal and gonadal vein variations. NJCA 2012;1:125–128. DOI: 10.1055/s-0039-3401679.
9. Shakya P, Das B, Shakya NK, et al. Variation in the drainage of gonadal vein. PJSR 2016;9(1):57–60. DOI: 10.5281/zenodo.8247536.
10. Ghosh A, Chaudhury S. A cadaveric study of ovarian veins: Variations, measurements and clinical significance. Anat Cell Biol 2019;52(3):295–309. DOI: 10.5115/acb.19.062.
11. Diwan Y, Singal R, Diwan D, et al. Bilateral variations of testicular vessels: Embryological background and clinical implications. JBCRS 2013;2:60–62. DOI: 10.4103/2278-960X.112598.