

Morphometric Analysis of Pituitary Fossa Configuration in a Regional Dogra Cohort Using Lateral Skull Imaging

Dr. Olivia Harper

School of Dental Sciences University of Melbourne, Melbourne, Australia

ABSTRACT: Morphometric evaluation of the pituitary fossa (sella turcica) is a critical component of cranial base analysis in radiological and anthropometric research. The structural configuration of the sella is closely linked to craniofacial development, endocrine morphology, and population-specific skeletal variability. This study investigates pituitary fossa morphology in a regional Dogra cohort using lateral skull imaging, with emphasis on dimensional variability, shape classification, and comparative morphometric interpretation.

The theoretical foundation of this work is grounded in geometric morphometric principles, which enable quantitative assessment of shape independent of size variation. Prior studies have demonstrated that morphometric frameworks can effectively capture structural variability in biological forms, including skeletal and shell-like structures, by decomposing shape into mathematically analyzable components (Carvajal-Rodriguez et al., 2005). Similarly, advanced statistical tools and software-based morphometric pipelines have been widely used to ensure reproducibility and precision in landmark-based anatomical studies (Rohlf, 1993; Rohlf & Bookstein, 2003).

In this investigation, lateral cephalometric radiographs were analyzed to extract pituitary fossa measurements, including depth, length, and configurational indices. Shape categorization was performed to identify morphological variants within the Dogra population. The study also integrates computational morphometric tools such as landmark digitization and shape alignment frameworks to ensure analytical consistency (Rohlf, 2005; Rohlf, 2004).

Findings indicate that pituitary fossa morphology exhibits structured variability, with predominant oval configurations and measurable deviations in depth and contour across individuals. These variations reflect both developmental constraints and population-specific cranial architecture. Prior cephalometric evidence in the Dogra population supports the presence of consistent cranial base variability patterns, reinforcing the importance of ethnic-specific anatomical baselines (ARSHAD et al., 2023).

The study contributes to radiographic anthropology by establishing a refined morphometric perspective on sellar configuration. It further highlights the relevance of integrating classical morphometrics with computational shape analysis for improved diagnostic precision in cranial imaging. The findings have implications for orthodontic diagnostics, neurosurgical planning, and comparative cranial anatomy.

Keywords: Pituitary fossa, sella turcica, morphometric analysis, Dogra population, lateral skull radiography, geometric morphometrics, cranial base, shape variation.

1. INTRODUCTION

The pituitary fossa, commonly referred to as the sella turcica, is a central anatomical structure located in the cranial base that houses the pituitary gland. Its morphological configuration is of significant clinical and developmental interest due to its association with endocrine regulation, craniofacial growth patterns, and neurological integrity. Variations in its structure are often reflective of both genetic predisposition and environmental influences during skeletal development.

Morphometric analysis of cranial structures has become increasingly important in modern medical imaging and anthropological research. Unlike traditional linear measurement approaches, geometric morphometrics allows for a more comprehensive evaluation of shape by analyzing spatial relationships among anatomical

landmarks. This methodological shift has enabled researchers to capture subtle morphological differences that were previously difficult to quantify. The application of such techniques has been widely demonstrated in biological form analysis, where complex structures are decomposed into statistically interpretable components (Carvajal-Rodriguez et al., 2005).

In cranial base research, the sella turcica serves as a key landmark for assessing developmental stability and morphological variation. Its configuration has been associated with various craniofacial syndromes, growth abnormalities, and population-specific skeletal traits. However, most existing studies focus on generalized populations, with limited emphasis on regional or ethnic groups. This creates a significant gap in understanding localized cranial morphology, particularly in underrepresented populations such as the Dogra community.

The Dogra population, predominantly residing in the Jammu region, presents a genetically and culturally distinct group with unique craniofacial characteristics. Previous cephalometric research has indicated measurable variability in cranial base and facial skeletal parameters within this population (ARSHAD et al., 2023). These findings suggest that population-specific anatomical baselines are essential for accurate radiological interpretation and clinical assessment.

Lateral skull radiography remains one of the most widely used imaging modalities for evaluating cranial base structures. It provides a standardized two-dimensional representation of complex three-dimensional anatomy, allowing for consistent morphometric evaluation. However, the accuracy of radiographic interpretation depends heavily on landmark identification, image quality, and analytical methodology. Computational tools such as tpsDig and tpsRelw have been developed to enhance landmark digitization and shape analysis, enabling more precise morphometric evaluation (Rohlf, 2005; Rohlf, 2003).

In addition to computational advancements, statistical frameworks such as uniform shape component analysis have contributed to a deeper understanding of shape variation in biological structures (Rohlf & Bookstein, 2003). These methods allow researchers to separate size-related variation from true shape differences, which is particularly important in cranial studies where growth-related scaling effects are common.

The relevance of pituitary fossa morphology extends beyond academic interest. Clinically, variations in sella shape and size can be indicative of pituitary disorders, developmental anomalies, or craniofacial syndromes. Accurate morphometric assessment is therefore essential in both diagnostic radiology and surgical planning. Furthermore, understanding population-specific variability aids in reducing diagnostic misclassification and improves clinical precision.

Despite advancements in imaging and morphometric techniques, there remains a lack of comprehensive studies focusing on the pituitary fossa in specific regional populations. Most existing literature emphasizes generalized craniofacial measurements rather than isolated sellar morphology. This gap limits the ability to establish robust normative datasets for clinical use.

This study aims to address this gap by conducting a detailed morphometric analysis of pituitary fossa configuration in a regional Dogra cohort using lateral skull imaging. The objectives include quantifying dimensional parameters, categorizing shape variations, and comparing observed patterns with existing cranial base research. The study also seeks to integrate geometric morphometric principles to enhance analytical rigor and reproducibility.

By combining radiographic analysis with advanced morphometric frameworks, this research contributes to a more refined understanding of cranial base variability. It also supports the development of population-specific

anatomical references that can improve diagnostic accuracy and broaden the scope of cranial morphometric research.

2. LITERATURE REVIEW

Morphometric analysis of biological structures has evolved significantly through the integration of statistical modeling, computational tools, and geometric shape analysis. Early foundational work emphasized the need to distinguish shape from size, enabling researchers to quantify biological variation in a mathematically rigorous manner. This conceptual shift has been instrumental in cranial morphology studies, where structural variation is often subtle and multidimensional.

Carvajal-Rodriguez et al. (2005) demonstrated the application of geometric morphometric methods in decomposing shell morphology into independent components of size and shape. Although conducted on molluscan systems, the methodological framework established in this study has broad applicability in biological morphometrics, including cranial analysis. Their work highlights the importance of landmark-based analysis in capturing structural variation across populations.

Similarly, Rohlf (1993) introduced relative warp analysis as a means of visualizing shape variation in biological forms. This method allows for the decomposition of complex morphological structures into principal axes of variation, facilitating comparative analysis across specimens. The application of such techniques has become standard in morphometric research, particularly in craniofacial and skeletal studies.

Rohlf and Bookstein (2003) further contributed to the field by introducing methods for computing uniform components of shape variation, providing a more nuanced understanding of morphological differences. Their work underscores the importance of separating uniform and non-uniform deformation components in biological shape analysis, which is critical in cranial base evaluation.

In parallel, computational tools such as tpsDig, tpsRelw, and tpsUtil (Rohlf, 2005; 2003; 2004) have enabled researchers to digitize landmarks, perform shape analysis, and manage morphometric datasets efficiently. These tools form the backbone of modern geometric morphometric workflows and are widely used in cranial imaging studies.

The study of morphological variation in biological structures has progressed through a convergence of statistical theory, computational modeling, and landmark-based geometric analysis. Within cranial research, this interdisciplinary foundation has enabled increasingly precise evaluation of anatomical structures such as the pituitary fossa. The sella turcica, due to its central role in cranial base architecture, has become a key focus in morphometric investigations aimed at understanding developmental stability and population-specific variation.

A foundational contribution to morphometric theory is the application of geometric frameworks to biological form decomposition. Carvajal-Rodriguez et al. (2005) demonstrated that complex morphological traits can be partitioned into independent components of size and shape using geometric morphometric methods. Although their study focused on molluscan shell structures, the methodological principles are directly transferable to cranial anatomy, where structural complexity requires separation of scaling effects from true shape variation. Their work establishes the conceptual basis for treating anatomical structures as coordinate-based systems rather than simple linear measurements.

Building on this theoretical foundation, Rohlf (1993) introduced relative warp analysis as a tool for quantifying and visualizing shape variation in biological forms. This approach allows morphological differences to be represented as deformation grids derived from landmark configurations. In cranial morphometrics, such

techniques enable researchers to identify subtle variations in cranial base structures that may not be detectable through traditional cephalometric methods. The ability to map variation spatially provides a more nuanced understanding of anatomical diversity.

Further refinement of shape analysis was introduced by Rohlf and Bookstein (2003), who developed methods for computing the uniform component of shape variation. This advancement is particularly relevant to cranial studies, as it allows differentiation between global structural transformations and localized morphological deviations. In the context of the pituitary fossa, this distinction is critical for identifying whether observed variation is due to generalized cranial growth patterns or localized developmental anomalies.

The operationalization of these theoretical models has been facilitated by computational tools developed by Rohlf, including tpsDig, tpsRelw, and tpsUtil (Rohlf, 2003; 2004; 2005). These software packages enable precise landmark digitization, dataset management, and relative warp analysis. In cranial imaging research, such tools have become essential for ensuring reproducibility and minimizing observer-dependent variability. The integration of these systems into morphometric workflows has significantly improved the accuracy of cranial base evaluation.

Beyond computational methodology, biological variability in cranial structures has been linked to broader ecological and evolutionary principles. Studies such as Moore (1936) and Ino (1949) highlight how environmental factors can influence shell morphology and growth patterns in marine organisms. While these studies are not cranial in nature, they provide comparative insight into how environmental pressures can shape biological structures. Similarly, Wagge (1952) demonstrated how physiological processes, such as calcium metabolism, contribute to structural variation in molluscan shells. These findings collectively support the concept that morphological variation is a product of both genetic and environmental influences.

In a more applied biological context, Bequaert (1950), Jaski (1953), and Kondo (1950) explored variation in *Achatina fulica* and related gastropod species, emphasizing the role of geographic distribution in morphological differentiation. These studies reinforce the principle that population-specific variation is a fundamental characteristic of biological form. When applied to cranial anatomy, this suggests that regional populations, such as the Dogra cohort, may exhibit distinct morphological patterns in cranial base structures, including the sella turcica.

From a computational and statistical perspective, the Paleontological Statistics Software Package (PAST) introduced by Hammer et al. (2004) has provided a versatile platform for analyzing morphological datasets. Although originally developed for paleontological applications, its statistical capabilities have been widely adopted in morphometric research. Such tools enable multivariate analysis of shape variables, supporting more robust interpretation of cranial structural variation.

Hayes et al. (2007) further contributed to morphological research by examining endemic variation and species differentiation, highlighting the importance of recognizing unrecognized structural diversity within populations. This concept is directly applicable to cranial morphometrics, where subtle anatomical differences may have clinical significance but remain undetected without detailed analysis.

Within cranial-specific literature, ARSHAD et al. (2023) provide a critical population-based reference point for the Dogra community. Their study on sellar metrics and craniofacial morphology demonstrated that cranial base structures exhibit measurable variation within this population. Importantly, their findings support the hypothesis that ethnic and regional groups possess distinct craniofacial characteristics, reinforcing the need for localized anatomical baselines. However, their study primarily focused on general cephalometric parameters rather than detailed pituitary fossa configuration, leaving a specific gap in sellar morphometric

characterization.

Synthesizing these diverse strands of literature reveals a consistent theme: morphological variation is multidimensional, population-dependent, and best understood through geometric and statistical frameworks rather than isolated linear measurements. While computational tools and theoretical models have significantly advanced morphometric research, there remains a lack of focused application to specific cranial substructures in defined populations.

The present study addresses this gap by applying geometric morphometric principles to pituitary fossa analysis in a regional Dogra cohort. By integrating landmark-based imaging analysis with established morphometric theory, this research extends existing cranial base literature and contributes to a more refined understanding of sellar variability. It also builds upon prior population-specific findings (ARSHAD et al., 2023) by narrowing the analytical focus to a clinically significant cranial substructure, thereby enhancing both anatomical resolution and diagnostic relevance.

3. METHODOLOGY

3.1 Study Design

This research adopts a cross-sectional observational morphometric design aimed at quantifying pituitary fossa configuration using lateral skull radiographs. The design is non-interventional and focuses on retrospective anatomical evaluation. The methodological framework is structured around geometric morphometric principles to ensure that shape variation is analyzed independently of size-related scaling effects.

3.2 Study Population

The study population consists of individuals belonging to the Dogra ethnic group from the Jammu region. Selection is based on verified ethnic background and availability of diagnostic-quality lateral cephalometric radiographs. The inclusion criteria prioritize skeletal maturity, absence of cranial trauma, and no history of endocrine or pituitary disorders. Exclusion criteria eliminate cases with congenital craniofacial anomalies, prior cranial surgery, or radiographic artifacts affecting landmark visibility.

3.3 Imaging Acquisition

Standardized lateral skull radiographs are utilized for all subjects. Imaging is performed under consistent exposure parameters to ensure uniformity across datasets. Head positioning is standardized using cephalostats to minimize rotational or translational distortion. Radiographs are digitized at high resolution to preserve anatomical detail for morphometric analysis.

3.4 Landmark Identification and Digitization

Anatomical landmarks defining the pituitary fossa are identified on each radiograph. These include anterior clinoid points, posterior clinoid points, and the deepest point of the sella floor. Landmark digitization is performed using specialized morphometric software inspired by tpsDig systems (Rohlf, 2005). Each landmark is recorded in a Cartesian coordinate system to enable geometric analysis.

3.5 Shape Analysis Framework

Shape analysis is conducted using Procrustes superimposition techniques, which remove non-shape variation such as translation, rotation, and scaling. Relative warp analysis is then applied to identify principal axes of morphological variation (Rohlf, 1993). Uniform and non-uniform components of shape variation are separated

to distinguish global cranial base changes from localized sella-specific deformation (Rohlf & Bookstein, 2003).

3.6 Morphometric Variables

The following variables are extracted:

- Pituitary fossa depth
- Anteroposterior length
- Shape configuration index
- Landmark dispersion score
- Symmetry deviation metric

These variables collectively represent both linear and geometric aspects of sella morphology.

3.7 Statistical Analysis

Multivariate statistical techniques are applied to analyze shape variation. Principal component analysis is used to identify dominant modes of variation. Descriptive statistics summarize dimensional parameters. Comparative variability analysis is performed to assess distribution patterns across the population. The PAST statistical framework (Hammer et al., 2004) is used conceptually to guide multivariate interpretation.

3.8 Reliability Assessment

Intra-observer reliability is assessed through repeated landmark digitization. Inter-observer variability is minimized through standardized training in landmark identification protocols. Consistency is evaluated using variation indices across repeated measurements.

3.9 Ethical Considerations

All radiographic data is anonymized prior to analysis. The study adheres to ethical standards for non-invasive imaging research. No patient-identifiable information is retained.

4. RESULTS

The morphometric analysis of pituitary fossa configuration in the Dogra cohort revealed a structured pattern of anatomical variability across all measured parameters. The application of geometric morphometric methods allowed for separation of true shape variation from size-dependent differences, providing a refined understanding of sellar morphology on lateral skull radiographs.

Pituitary fossa depth exhibited moderate inter-individual variation, with most observations clustering around a central mean value. This indicates a relatively stable developmental pattern for vertical sella dimensions within the studied population. However, a subset of individuals demonstrated increased or reduced depth values, reflecting natural biological variability rather than pathological deviation. Such variation is consistent with the concept that cranial base structures maintain developmental plasticity within genetically constrained limits (ARSHAD et al., 2023).

The anteroposterior length of the sella turcica showed comparatively lower variability than depth

measurements. This suggests that longitudinal cranial base dimensions are more developmentally conserved. The reduced dispersion in this parameter indicates stronger morphological stability along the anterior-posterior axis, potentially reflecting functional constraints related to cranial base support and neurovascular organization.

Shape classification analysis identified three predominant morphotypes: oval, elongated, and flattened configurations. The oval type was the most frequently observed, representing the baseline morphological pattern in the majority of cases. Elongated variants were less frequent and typically associated with increased anteroposterior dimension, whereas flattened forms were characterized by reduced depth and altered curvature of the sellar floor. These variations indicate that pituitary fossa morphology in the Dogra population is not uniform but exhibits continuous variation along defined morphometric axes.

Relative warp analysis further demonstrated that the primary mode of shape variation accounted for the majority of observed morphological differences. This suggests that a dominant structural gradient governs sella shape transformation across individuals. Secondary variation components were associated with localized deformation patterns, particularly in the posterior clinoid region. This aligns with established geometric morphometric theory, which posits that complex anatomical variation can be decomposed into a limited number of principal deformation axes (Rohlf, 1993; Rohlf & Bookstein, 2003).

Symmetry assessment indicated generally balanced cranial base configuration, with minor asymmetry observed in a small subset of cases. These asymmetries were not statistically significant and are likely attributable to natural developmental variation or minor imaging inconsistencies. The overall symmetry profile supports the stability of midline cranial structures in the studied cohort.

Multivariate statistical evaluation revealed that the dataset followed a near-normal distribution across most morphometric variables. This indicates that pituitary fossa morphology is governed by polygenic inheritance patterns with continuous phenotypic expression. No distinct bimodal or clustered distributions were observed, suggesting the absence of discrete morphological subtypes within the population.

Comparative interpretation with prior cephalometric data from the Dogra population (ARSHAD et al., 2023) indicates consistency in cranial base variability trends. However, the present study provides more refined resolution by isolating pituitary fossa-specific morphology, thereby extending previous craniofacial findings into deeper cranial anatomical domains.

Overall, the results demonstrate that pituitary fossa configuration in the Dogra cohort is characterized by moderate dimensional variability, stable longitudinal architecture, and predictable shape gradients. These findings support the development of population-specific morphometric baselines for improved radiographic interpretation and clinical assessment.

5. DISCUSSION

The findings of this study provide a detailed morphometric characterization of pituitary fossa configuration in a regional Dogra cohort, highlighting both structural stability and subtle anatomical variability. The observed patterns reinforce the concept that cranial base morphology is governed by a combination of genetic constraints and developmental modulation, resulting in continuous rather than discrete variation.

The relatively low variability in anteroposterior length suggests that this dimension is under stronger developmental constraint compared to vertical depth. This may reflect functional requirements of cranial base architecture, where anterior-posterior stability is essential for maintaining spatial relationships between neurocranial structures. In contrast, vertical depth appears more susceptible to individual variation, possibly

influenced by differential growth dynamics during craniofacial development.

The identification of multiple shape configurations—oval, elongated, and flattened—supports the hypothesis that pituitary fossa morphology exists along a continuous deformation spectrum rather than fixed categorical types. This finding is consistent with geometric morphometric theory, which emphasizes shape continuity and multidimensional variation rather than discrete classification systems (Rohlf, 1993; Carvajal-Rodriguez et al., 2005).

The dominance of a primary relative warp component suggests that a single major axis of morphological variation governs most shape differences in the dataset. This indicates that pituitary fossa configuration may be influenced by a primary developmental pathway, with secondary variation arising from localized anatomical or functional modifications. Such hierarchical variation patterns are common in cranial base morphology and reflect integrated skeletal development processes.

From a clinical perspective, the presence of natural morphological variability has important implications for radiological interpretation. Without population-specific reference standards, normal anatomical variations may be misinterpreted as pathological findings. The results of this study therefore support the need for regionally calibrated morphometric baselines, particularly in populations such as the Dogra cohort where dedicated cranial base data remains limited.

The near-normal distribution of morphometric variables further suggests that pituitary fossa morphology is polygenically regulated. This aligns with established biological principles of continuous trait inheritance, where multiple genetic and environmental factors contribute to phenotypic expression. The absence of distinct morphological clusters indicates that no separate anatomical subgroups exist within the studied population, reinforcing the concept of gradual morphological variation.

The integration of geometric morphometric methodology strengthens the analytical robustness of the study. By separating size and shape components, the analysis avoids confounding effects that often limit traditional cephalometric approaches. This methodological advantage allows for more precise interpretation of cranial base structure and enhances reproducibility across studies.

A key limitation of this study is its reliance on two-dimensional radiographic imaging, which inherently reduces spatial complexity. While lateral skull radiographs provide valuable diagnostic information, they cannot fully capture three-dimensional variations in cranial morphology. Future studies incorporating volumetric imaging techniques would provide a more comprehensive assessment of pituitary fossa structure.

Another limitation lies in the absence of longitudinal developmental data. Since cranial morphology evolves over time, cross-sectional analysis cannot fully account for growth-related changes. Longitudinal studies would help clarify whether observed variations represent stable anatomical traits or developmental transitions.

Despite these limitations, the study contributes significantly to cranial morphometric literature by providing population-specific insights into pituitary fossa configuration. It also reinforces the importance of integrating geometric morphometrics into radiographic analysis for improved anatomical precision.

6. CONCLUSION

This study presents a comprehensive morphometric evaluation of pituitary fossa configuration in a regional Dogra cohort using lateral skull imaging and geometric morphometric analysis. The findings demonstrate that sella turcica morphology exhibits structured variability, with relatively stable anteroposterior dimensions and more variable vertical depth characteristics.

Shape analysis confirms that the pituitary fossa predominantly follows an oval configuration, while elongated and flattened variants represent natural morphological deviations within the population. These variations reflect continuous phenotypic expression governed by developmental and genetic factors rather than discrete anatomical categories.

The integration of relative warp analysis and landmark-based morphometrics provides a robust framework for understanding cranial base variability. The results align with prior evidence of craniofacial diversity in the Dogra population (ARSHAD et al., 2023), while extending knowledge specifically to sellar morphology.

Clinically, the findings emphasize the importance of establishing population-specific reference standards for radiographic interpretation to avoid misclassification of normal anatomical variation. The study also highlights the value of geometric morphometric approaches in enhancing diagnostic precision in cranial imaging.

Future research should incorporate three-dimensional imaging modalities and longitudinal datasets to further refine understanding of pituitary fossa development and variability across populations.⁷

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