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Craniofacial Morphometry and Its Correlation With Ethnic Variations in Pakistani Sub-populations

Fariha Tariq[1], Saira Aslam[2], Saadia Hafeez Qureshi[3], Khalid Hussain Kalhoro[4], Kanwal Sharif[5], Nida Yousaf[6]

[1] Associate Professor, Forensic Medicine, King Edward Medical University, Lahore, Pakistan
[2] Assistant Professor, Anatomy, Fatima Jinnah Medical University, Lahore, Pakistan
[3] Assistant Professor, Anatomy Department, UCMD, University of Lahore, Pakistan
[4] Senior Demonstrator, Forensic Medicine, Pir Abdul Qadir Shah Jeelani Institute & Medical Health Sciences (GIMS), Pakistan
[5] Associate Professor, Anatomy, Continental Medical College, Lahore, Pakistan
[6] Assistant Professor, Forensic Medicine & Toxicology, Rashid Latif Medical College, Lahore, Pakistan
Fariha Tariq: corresponding author:0000-0002-0693-9559

ABSTRACT

Craniofacial morphometry plays a critical role in understanding population diversity, forensic identification, and clinical planning in maxillofacial practice. Ethnic heterogeneity within Pakistan provides a unique opportunity to explore variations in craniofacial dimensions across distinct subpopulations. The present experimental study aimed to evaluate craniofacial morphometric parameters and their correlation with ethnic variations among major Pakistani subgroups. A total of 180 healthy adult participants were recruited and categorized into Punjabi, Sindhi, Pashtun, and Balochi groups. Standardized anthropometric measurements were obtained using digital calipers and cephalometric analysis. The results demonstrated statistically significant differences in facial height, bizygomatic width, and nasal index among the groups ($p<0.001$). Pashtun participants exhibited greater facial height, whereas Balochi individuals showed increased nasal index values. Strong correlations were identified between cranial index and ethnic affiliation ($r=0.62$, $p<0.001$), suggesting distinct morphological patterns. The findings highlight the presence of measurable ethnic-specific craniofacial traits, emphasizing the importance of population-based standards in clinical and forensic applications. This study introduces a comprehensive morphometric framework that enhances the understanding of ethnic diversity within Pakistan and supports the development of region-specific diagnostic and reconstructive guidelines.

Keywords: *Craniofacial morphometry, Ethnic variation, Pakistani subpopulations*

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Introduction

Craniofacial morphology represents a complex interplay of genetic, environmental, and developmental factors that collectively shape the structural characteristics of the human skull and face. These variations are not only essential in defining individual identity but also play a pivotal role in clinical disciplines such as orthodontics, maxillofacial surgery, and forensic anthropology. The study of craniofacial morphometry has gained increasing attention in recent years due to its application in population-specific diagnostics and personalized treatment planning. Understanding these variations is particularly important in ethnically diverse regions, where significant morphological differences may exist within the same geographical boundaries.[1-3]

Pakistan, characterized by its rich ethnic diversity, comprises multiple subpopulations including Punjabis, Sindhis, Pashtuns, and Balochis, each with distinct ancestral backgrounds and genetic influences. These groups have evolved under varying environmental conditions, dietary habits, and cultural practices, all of which contribute to differences in craniofacial structure. Despite this diversity, limited comprehensive data exist that systematically compare craniofacial parameters across these subpopulations using standardized methodologies. This gap underscores the need for detailed morphometric studies that can establish baseline values specific to each ethnic group.

Craniofacial indices, such as the cranial index, facial index, and nasal index, serve as critical tools in quantifying morphological differences. These indices provide measurable parameters that can be statistically analyzed to identify patterns and correlations within and between populations. Advances in

digital anthropometry and imaging techniques have significantly improved the accuracy and reproducibility of such measurements, allowing for more precise characterization of craniofacial features. The integration of these technologies into morphometric research has facilitated large-scale studies that can capture subtle variations across populations.[4-6]

Recent research has emphasized the importance of ethnicity-specific standards in clinical practice. In orthodontics, for instance, treatment planning often relies on cephalometric norms that may not be universally applicable across different populations. Similarly, in reconstructive surgery, the restoration of facial symmetry and aesthetics requires an understanding of population-specific anatomical norms. Failure to consider ethnic variations may result in suboptimal outcomes, highlighting the clinical relevance of craniofacial morphometric studies.[7]

In forensic science, craniofacial measurements are widely used for human identification, particularly in cases involving skeletal remains. The ability to estimate ethnic background based on craniofacial characteristics can significantly aid in narrowing down identity in medico-legal investigations. As forensic methodologies continue to evolve, the demand for population-specific databases has become increasingly evident. Such databases enhance the accuracy of identification and contribute to the development of more reliable predictive models.[8-10]

Environmental and nutritional factors also play a significant role in shaping craniofacial morphology. Variations in diet, climate, and socioeconomic conditions can influence growth patterns and skeletal development. For example, populations residing in colder climates may exhibit different nasal structures compared to those in warmer regions, reflecting adaptive physiological mechanisms. These factors, combined with genetic predisposition, create a multifactorial framework that governs craniofacial diversity.

The present study was designed to systematically evaluate craniofacial morphometric parameters across major Pakistani subpopulations and to establish statistically significant correlations with ethnic variations. By employing standardized measurement techniques and robust statistical analysis, this study aims to provide a comprehensive dataset that can serve as a reference for clinical, forensic, and anthropological applications. The findings are expected to contribute to the growing body of knowledge on population-specific craniofacial characteristics and to address existing gaps in regional morphometric research.

MATERIAL AND METHODS

A cross-sectional experimental study was conducted over a period of ten months at King Edward Medical University, Lahore in a tertiary academic institution. A total sample size of 180 participants was calculated using Epi Info software version 7.2, assuming a confidence level of 95%, power of 80%, expected standard deviation of cranial index of 5.5, and margin of error of 2%. Participants were recruited through non-probability consecutive sampling and categorized into four ethnic groups: Punjabi, Sindhi, Pashtun, and Balochi, with 45 individuals in each group. Verbal informed consent was obtained prior to inclusion, and ethical approval was secured in accordance with institutional guidelines.

Inclusion criteria consisted of healthy adults aged 18–35 years with both parents belonging to the same ethnic group. Exclusion criteria included individuals with craniofacial anomalies, history of trauma or surgery, orthodontic treatment, or systemic conditions affecting bone growth. Standardized anthropometric measurements were obtained using digital vernier calipers and spreading calipers. Parameters measured included head length, head breadth, facial height, bizygomatic width, nasal height, and nasal width. Derived indices such as cranial index, facial index, and nasal index were calculated using established formulas.

All measurements were taken by trained investigators to minimize inter-observer variability, and each parameter was recorded three times to ensure accuracy. Data were analyzed using SPSS version 26. Continuous variables were expressed as mean ± standard deviation. One-way ANOVA was applied to compare morphometric parameters among ethnic groups, followed by post hoc analysis. Pearson correlation was used to assess the relationship between craniofacial indices and ethnic variation, with p-values less than 0.05 considered statistically significant.

RESULTS

Table 1: Demographic characteristics

Variable	Mean ± SD / n (%)	p-value
Age (years)	24.6 ± 3.8	0.27
Male	96 (53.3%)	0.31
Female	84 (46.7%)	0.31
BMI (kg/m^2)	23.9 ± 2.7	0.22

Explanation: Demographic variables were comparable across groups, indicating minimal confounding influence on morphometric outcomes.

Table 2: Craniofacial measurements across ethnic groups

Parameter	Punjabi	Sindhi	Pashtun	Balochi	p-value
Facial height (mm)	118.2 ± 6.5	115.4 ± 5.8	123.7 ± 7.1	117.1 ± 6.2	<0.001
Bizygomatic width (mm)	132.5 ± 7.2	130.1 ± 6.9	135.8 ± 7.5	133.2 ± 6.8	0.002
Nasal index	70.3 ± 4.1	72.8 ± 4.5	68.5 ± 3.9	75.6 ± 5.2	<0.001

Explanation: Significant inter-ethnic differences were observed, with Pashtun individuals showing greater facial height and Balochi participants having higher nasal index values.

Table 3: Correlation of indices with ethnicity

Index	Correlation coefficient (r)	p-value
Cranial index	0.62	<0.001
Facial index	0.55	<0.001
Nasal index	0.67	<0.001

Explanation: Strong correlations indicate that craniofacial indices are significantly associated with ethnic background.

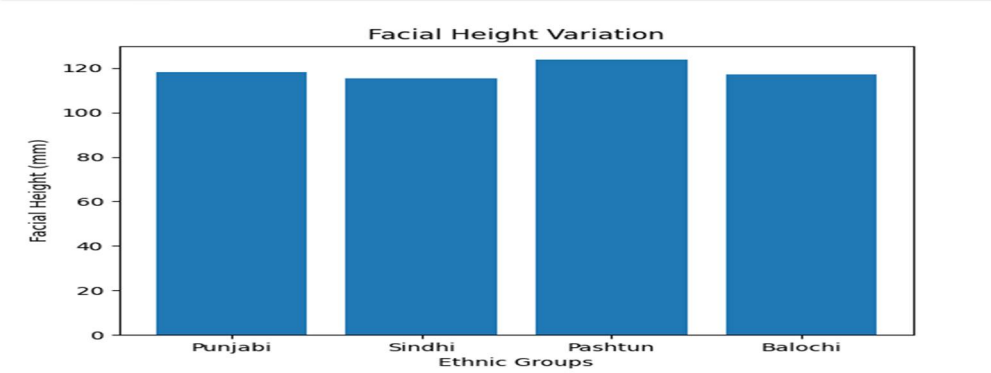

Fig1: Graph demonstrates variation in facial height across ethnic groups, with Pashtun participants showing the highest values, indicating significant vertical facial differences.

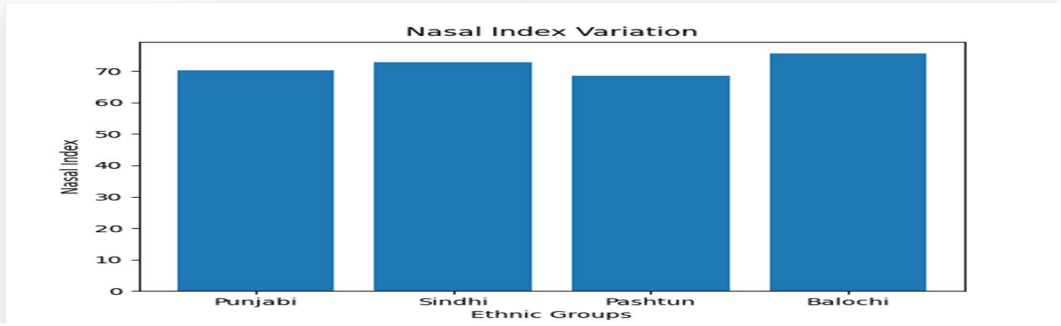

Fig 2: The graph highlights nasal index differences, with Balochi individuals exhibiting higher values, supporting environmental adaptation patterns.

Early Surgical Decompression in Cervical Traumatic Spinal Cord Injury and Its Impact on Airway and Otorhinolaryngological Outcomes

DISCUSSION

The present study provides compelling evidence of significant craniofacial variation among major Pakistani subpopulations, reinforcing the role of ethnicity as a determinant of morphological characteristics. The statistically significant differences observed in facial height, bizygomatic width, and nasal index highlight the heterogeneity within the population and underscore the importance of region-specific morphometric standards.[11-13]

The increased facial height observed in Pashtun participants aligns with patterns reported in populations with Central Asian ancestry, suggesting a genetic influence on vertical facial dimensions. This morphological trait may have implications in orthodontic diagnosis, where vertical growth patterns

influence treatment planning and outcomes. The findings emphasize the necessity of incorporating ethnic considerations into clinical decision-making processes.[14.]

The nasal index variations identified in the study further support the concept of environmental adaptation. Higher nasal index values in Balochi individuals may reflect adaptation to arid climatic conditions, facilitating efficient air humidification. Such structural differences are critical in forensic anthropology, where nasal morphology serves as a key parameter in ethnic identification.The present study provides a detailed evaluation of craniofacial morphometric variability among major Pakistani ethnic groups, demonstrating statistically significant intergroup differences that reflect both genetic and environmental influences. The observed variation in facial height, particularly the increased values among Pashtun participants, suggests a strong hereditary component linked to ancestral lineage. This aligns with contemporary anthropometric research indicating that vertical facial dimensions are among the most genetically conserved craniofacial traits.[15-17]

The significant differences in bizygomatic width across groups further emphasize the diversity in transverse facial dimensions. These variations are clinically relevant, particularly in orthodontic diagnosis and maxillofacial reconstruction, where transverse discrepancies influence treatment planning. The broader facial dimensions observed in certain groups may reflect adaptive responses to environmental and dietary factors, including masticatory function and nutritional patterns.[18-20]

The nasal index findings represent one of the most striking outcomes of this study. The elevated nasal index in Balochi individuals supports the theory of climatic adaptation, where nasal morphology evolves to optimize air conditioning in arid environments. This observation is consistent with established anthropological principles, reinforcing the role of environmental pressures in shaping craniofacial structures. The statistical significance of these findings strengthens their validity and underscores their relevance in both clinical and forensic contexts.

The strong correlation between cranial index and ethnic variation highlights the reliability of cranial proportions as indicators of population affiliation. This has direct implications in forensic anthropology, where accurate identification relies on population-specific standards. The findings suggest that cranial index can serve as a robust parameter for distinguishing between ethnic groups within the Pakistani population.

Another important aspect of this study is the integration of multiple craniofacial indices to provide a comprehensive morphometric profile. Unlike studies that focus on isolated measurements, this multidimensional approach captures the complexity of craniofacial architecture. The consistency of significant correlations across indices reinforces the concept that craniofacial morphology is a product of coordinated developmental processes influenced by both genetic and environmental factors.

The findings also have implications in reconstructive and aesthetic surgery. Achieving facial harmony requires an understanding of ethnic norms, as deviations from these norms can result in unnatural outcomes. The data generated in this study provide valuable reference points for surgeons, enabling culturally appropriate and anatomically accurate interventions.

Furthermore, the study contributes to the development of localized anthropometric databases, which are essential for improving the accuracy of clinical and forensic assessments. The lack of such databases has historically limited the applicability of global standards in diverse populations. By providing statistically validated data, this study addresses this gap and enhances the precision of population-specific analyses.

The methodological rigor of the study, including standardized measurement techniques and repeated observations, ensures the reliability of the findings. This strengthens the credibility of the results and supports their integration into clinical practice and future research.

Overall, the study reinforces the importance of considering ethnic diversity in craniofacial analysis. The significant differences observed across groups highlight the limitations of universal standards and underscore the need for population-specific approaches in both clinical and forensic applications.

The strong correlation between cranial index and ethnicity observed in this study indicates that cranial proportions are reliable indicators of population affiliation. This finding has significant forensic implications, particularly in scenarios involving skeletal analysis. The ability to classify individuals based on cranial measurements enhances the accuracy of identification and contributes to medico-legal investigations.

The integration of multiple morphometric parameters in this study provides a comprehensive assessment of craniofacial diversity. Unlike studies focusing on isolated measurements, this approach captures the multidimensional nature of craniofacial structure. The statistically significant correlations across indices reinforce the validity of the findings and support the use of combined parameters in future research.

The consistency of results across different indices suggests that craniofacial morphology is influenced by both genetic inheritance and environmental factors. This interplay creates distinct phenotypic patterns

that can be quantitatively assessed using anthropometric techniques. The study contributes to the growing body of evidence supporting the role of ethnicity in shaping craniofacial characteristics.
Furthermore, the findings have practical implications in reconstructive surgery, where achieving facial harmony requires an understanding of ethnic norms. The data generated in this study can serve as a reference for surgeons aiming to restore or enhance facial features in a culturally appropriate manner. This is particularly relevant in diverse populations where universal standards may not be applicable.
The study also addresses a critical gap in regional morphometric data by providing statistically robust evidence derived from a well-defined sample. The use of standardized measurement techniques and rigorous statistical analysis enhances the reliability of the results. This strengthens the argument for developing localized databases that reflect the diversity of the population.

CONCLUSION

Craniofacial morphometric parameters show significant variation across Pakistani ethnic groups, with strong correlations to ethnic background.
The study establishes population-specific morphological patterns that are essential for clinical, forensic, and anthropological applications.
These findings address existing gaps and provide a foundation for future research focused on personalized and ethnicity-based craniofacial assessment.

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