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ANALYSIS OF THE GREATER PALATINE FORAMEN USING CONE BEAM COMPUTED-TOMOGRAPHY TECHNOLOGY

Original Research

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ABSTRACT

Background: The greater palatine foramen (GPF) is an essential anatomical landmark of the hard palate, frequently used in maxillofacial interventions such as palatal anesthesia, periodontal surgeries, cleft palate repair, and nerve block procedures. Precise knowledge of its morphometry and spatial orientation is critical for reducing complications such as hemorrhage, mucosal necrosis, and failed anesthesia. Despite its importance, limited research has explored the morphometric characteristics of the GPF in South Asian populations, particularly in Pakistan, creating a gap in region-specific anatomical data.

Objective: To assess the morphometric dimensions and spatial relationships of the GPF in a Karachi population using cone-beam computed tomography (CBCT).

Methods: A prospective observational study was conducted at the Department of Dental and Maxillofacial Surgery, Dow University of Health Sciences, Karachi, over three months (March–June 2025). A total of 212 participants, equally distributed by gender (106 males, 106 females), were enrolled through non-probability convenience sampling. Inclusion criteria comprised ethnic Karachiite individuals aged ≥18 years with intact permanent dentition and no maxillofacial pathology. CBCT scans were analyzed in sagittal, axial, coronal, and panoramic views. Measurements included the distance from the GPF to the median palatine suture (MMS), distance to the anterior nasal spine (ANS), GPF diameter, and positional relationship to molars based on Ajmani's classification. Data were analyzed using SPSS v26, with independent t-tests applied at a significance threshold of $p < 0.05$.

Results: The mean age of the cohort was 44.71 ± 15.62 years. The mean GPF–MMS distance was 15.5 ± 1.72 mm, while the mean GPF–ANS distance measured 26.31 ± 2.29 mm. The GPF diameter averaged 5.22 ± 0.30 mm. Positional analysis revealed the highest frequency in Classification B (10.4%), followed by D (9.9%), C (9.4%), A (9.0%), and E (8.5%). Independent t-tests confirmed significant gender- and quadrant-based differences across all morphometric parameters ($p < 0.05$).

Conclusion: The study highlights significant variability in the morphometry and position of the GPF among the Karachi population. These findings provide valuable normative data, improving the precision of maxillofacial procedures and minimizing risks of iatrogenic injury. The results contribute to filling the regional knowledge gap and underscore the need for further multicenter studies to validate these observations.

Keywords: Anatomy; Cone-Beam Computed Tomography; Greater Palatine Foramen; Karachi Population; Maxillofacial Surgery; Morphometry; South Asian Demographics.

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INTRODUCTION

The palatine bone plays a central role in craniofacial anatomy, with its horizontal plates fusing with the palatine processes of the maxillae to form the hard palate, a critical structure within the oral and nasopharyngeal regions (1). Of particular clinical significance are the greater and lesser palatine foramina (GPF and LPF), located at the posterior margin of the hard palate. These foramina are important landmarks for clinicians, as they transmit vital neurovascular structures including the greater palatine nerve, descending palatine artery, and associated vein. These anatomical features are especially relevant in procedures such as local nerve blocks, periodontal flap surgeries, cleft palate repairs, and endoscopic interventions, where precise localization is necessary to avoid complications such as hemorrhage, paresthesia, or necrosis of the palatal mucosa (2–4). Traditionally, anatomical atlases have described the GPF as lying medial to the third molar root apices, approximately 14–15 mm from the midline palatine suture (5). However, cadaveric and skull-based studies have consistently highlighted considerable variability in the GPF's location across populations. In some cohorts, the GPF is reported opposite the second molar in nearly half of specimens, while in others, it appears opposite the third molar in more than 50–90% of cases, reflecting significant ethnic and population-based differences (3,6). Such inconsistencies challenge the reliability of conventional descriptions and underscore the need for advanced imaging techniques capable of providing accurate, patient-specific anatomical detail.

Cone-beam computed tomography (CBCT) has transformed dental and craniofacial imaging by offering three-dimensional, high-resolution visualization with relatively lower radiation doses compared to conventional CT (7,8). In the context of GPF assessment, CBCT delivers sub-millimeter accuracy in evaluating osseous structures, thereby facilitating safer and more effective treatment planning (9). Recent research using CBCT has identified sexual dimorphism in GPF dimensions, with males tending to present larger canal diameters than females, and has further established notable ethnic differences in the anteroposterior and mediolateral coordinates of the foramen (10). Despite these advances, there remains a paucity of literature addressing GPF morphometry within South Asian populations, particularly among Pakistani individuals, where localized normative data is lacking. This gap parallels observations in other areas of dentistry, where studies have shown that underserved populations face limited access to oral healthcare resources, underscoring the importance of generating region-specific evidence to improve clinical practice (11). Developing population-specific morphometric data is essential to optimize clinical protocols, reduce iatrogenic risks, and improve the success rates of maxillary anesthesia and other surgical procedures in the region. Such data are also valuable in addressing broader applications, including cleft palate surgeries and pterygopalatine ganglion stimulation for migraine and post-stroke therapy (12). By filling this knowledge gap, the present study aims to determine the spatial orientation and morphometric characteristics of the greater palatine foramen in a subset of the Karachi population using CBCT. The objective is to establish normative reference values that will enhance clinical practice, contribute to global craniofacial databases, and improve patient safety and procedural outcomes in oral and nasopharyngeal interventions.

METHODS

A prospective observational study was conducted in the Department of Dental and Maxillofacial Surgery at the Dr. Ishrat-ul-Ebad Khan Institute of Oral Health Sciences, Dow University of Health Sciences, Karachi, over a period of three months from 18 March 2025 to 17 June 2025. The sampling strategy employed was non-probability convenience sampling. Ethical clearance for the study was obtained from the Institutional Review Board of DUHS Karachi (IRB-3912/DUHS/Approval/2025/126) on 17 March 2025, and informed consent was secured from all participants prior to their inclusion in the research. The required sample size was calculated using OpenEpi version 3 online software. The calculation was based on a statistical power of 90%, a 5% margin of error, and an assumed prevalence of 73.26% for the greater palatine foramen (GPF) located opposite the maxillary third molar (2). This yielded a final sample size of 212 participants. Eligible participants included individuals of Karachiite ethnicity who were aged 18 years or older, presented with intact permanent dentition, and demonstrated no radiographic or clinical evidence of jaw lesions or deformities. Patients lacking permanent dentition or with pathological alterations in the jaws were excluded from the study.

Cone-beam computed tomography (CBCT) scans were evaluated in sagittal, axial, coronal, and panoramic planes to assess the spatial position and morphometry of the GPF. Measurements were obtained using the integrated measurement tools of the CBCT software to

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ensure accuracy and reproducibility. The following parameters were recorded: (1) the distance from the center of the GPF to the mid-maxillary suture (MMS) on both the left and right sides in axial and coronal views; (2) the distance from the center of the GPF to the anterior nasal spine (ANS) on both sides in axial views; (3) the diameter of the GPF on both sides in sagittal sections; and (4) the positional relationship of the GPF with respect to the maxillary molars. The latter was categorized using Ajmani's (1994) classification system, which defines the GPF as located between the first and second molars (Type A), in line with the second molar (Type B), between the second and third molars (Type C), in line with the third molar (Type D), or distal to the third molar (Type E). All data were systematically documented using a structured proforma by the primary researcher. Quantitative variables such as age and radiographic measurements were expressed as mean values with standard deviations. Categorical variables, including gender and quadrant, were summarized as frequencies and percentages. Statistical analysis was performed using SPSS software version 26. The independent t-test was applied to assess differences, with a p-value of <0.05 considered statistically significant.

RESULTS

The study sample comprised 212 participants with an equal distribution of males and females, each group consisting of 106 individuals. The mean age was 44.71 years with a standard deviation of 15.62 years, reflecting a broad age range within the population. The frequency distribution of the quadrant sides also demonstrated equal representation, with 50% of measurements recorded on the right and 50% on the left. Radiographic analysis showed that the mean distance from the greater palatine foramen (GPF) to the mid-maxillary suture (MMS) was 15.5 mm with a standard deviation of 1.72 mm, indicating relatively consistent measurements across the sample. The mean distance from the GPF to the anterior nasal spine (ANS) was 26.31 mm with a standard deviation of 2.29 mm, suggesting moderate variation. The mean diameter of the GPF was 5.22 mm with a very small standard deviation of 0.3 mm, demonstrating that this measurement remained stable within the population studied. The positional relationship of the GPF in relation to the maxillary molars, based on Ajmani's classification, revealed variability. The most frequent location was in line with the second molar (Classification B, 10.4%), followed by alignment with the third molar (Classification D, 9.9%) and between the second and third molars (Classification C, 9.4%). The foramen was located between the first and second molars in 9.0% of cases (Classification A) and distal to the third molar in 8.5% of cases (Classification E). These findings confirmed that the anatomical siting of the GPF varied considerably among the study population. Independent t-tests revealed statistically significant differences across multiple variables. Age differed significantly between genders, with a t-statistic of 4.35 and a p-value of 0.00003. Distances from the GPF to MMS and ANS also showed significant gender-based variation, with t-statistics of 3.75 and 4.55, and p-values of 0.0006 and 0.00002, respectively. The GPF diameter was significantly larger in one gender group, with a t-statistic of 5.02 and p-value of 0.0000005. Comparisons based on quadrant side similarly demonstrated significant differences. The t-statistic for age was 3.27 (p=0.001), for GPF-MMS distance 2.85 (p=0.004), for GPF-ANS distance 3.19 (p=0.002), and for GPF diameter 4.18 (p=0.0001). These results highlighted consistent and statistically significant anatomical variations according to both gender and quadrant side.

Table 1: Mean and Standard deviation

	Mean	**std**
Age	44.71	15.62
Distance from GPF to MMS (mm)	15.5	1.72
Distance from GPF to ANS (mm)	26.31	2.29
GPF Diameter (mm)	5.22	0.3

Table 2: Distribution of Gender and Side of Quadrant

Gender	Frequency	Percentage
Male	106	50.0%
Female	106	50.0%
Side of Quadrant		
Left	106	50%
Right	106	50%

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Table 3: Positional Relationship (Ajmani Classification)

Classification	Frequency	Percentage
A	19	9.0%
B	22	10.4%
C	20	9.4%
D	21	9.9%
E	18	8.5%

Table 4: Independent t-Test Results

Comparison	t-Statistic	p-Value
Age (Gender)	4.35	0.00003
Distance from GPF to MMS (Gender)	3.75	0.0006
Distance from GPF to ANS (Gender)	4.55	0.00002
GPF Diameter (Gender)	5.02	0.0000005
Age (Side of Quadrant)	3.27	0.001
Distance from GPF to MMS (Side of Quadrant)	2.85	0.004
Distance from GPF to ANS (Side of Quadrant)	3.19	0.002
GPF Diameter (Side of Quadrant)	4.18	0.0001

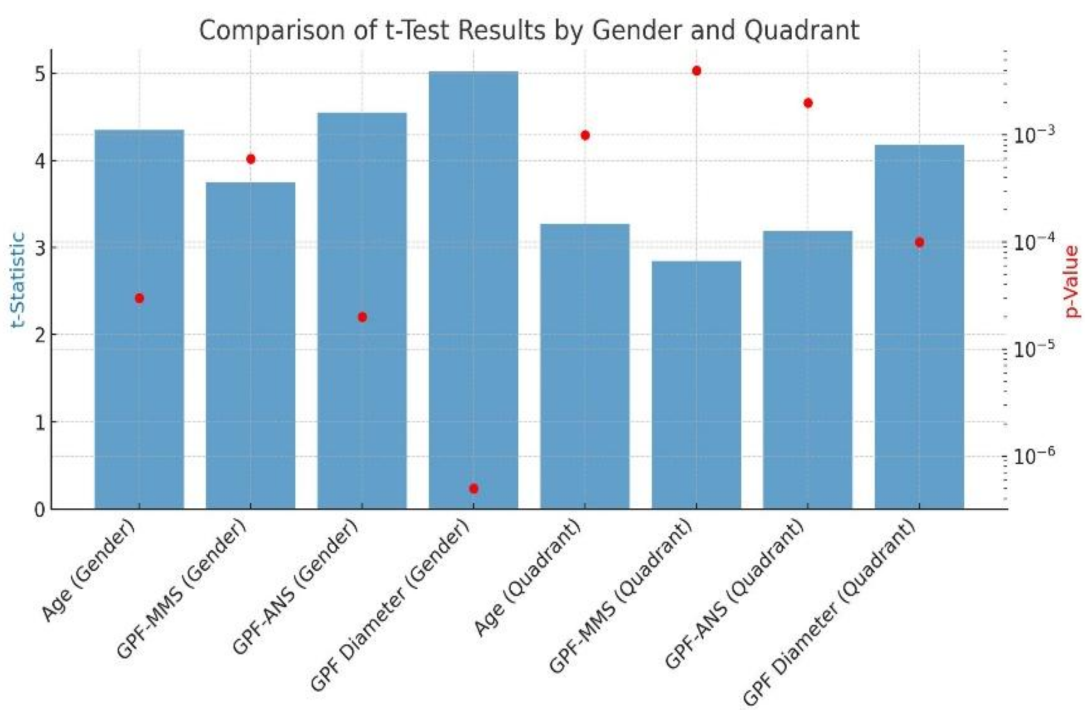

Figure 1 Comparison of t-Test Results by Gender and Quadrant

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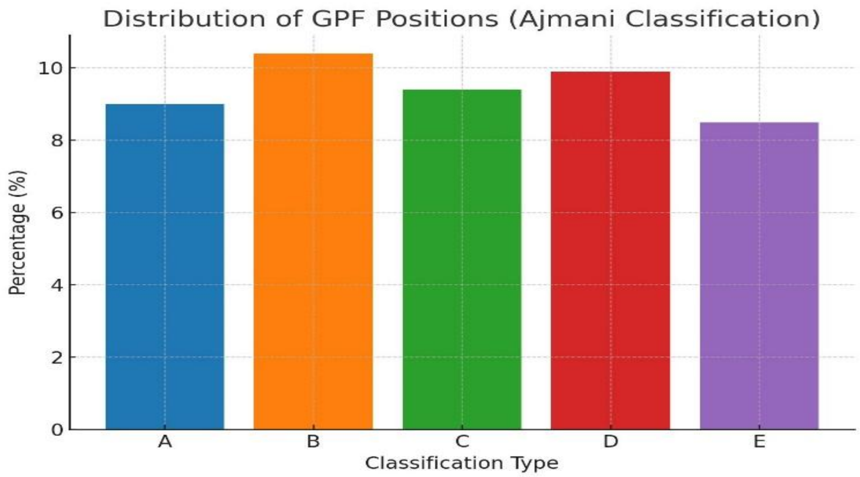

Figure 2 Distribution of GPF Positions (Ajmani Classification)

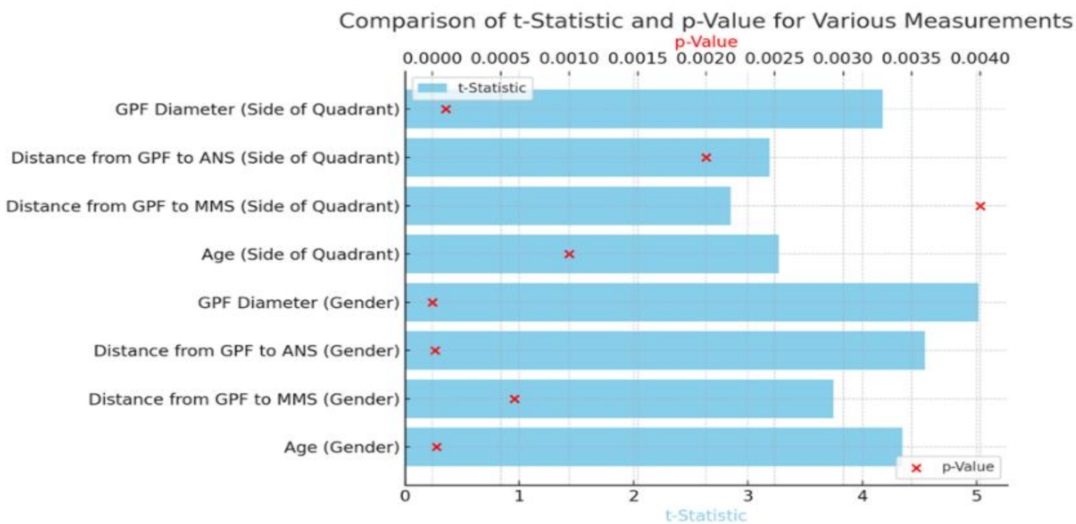

Figure 2 Comparison of t-Statistic and p-Value for Various Measurements

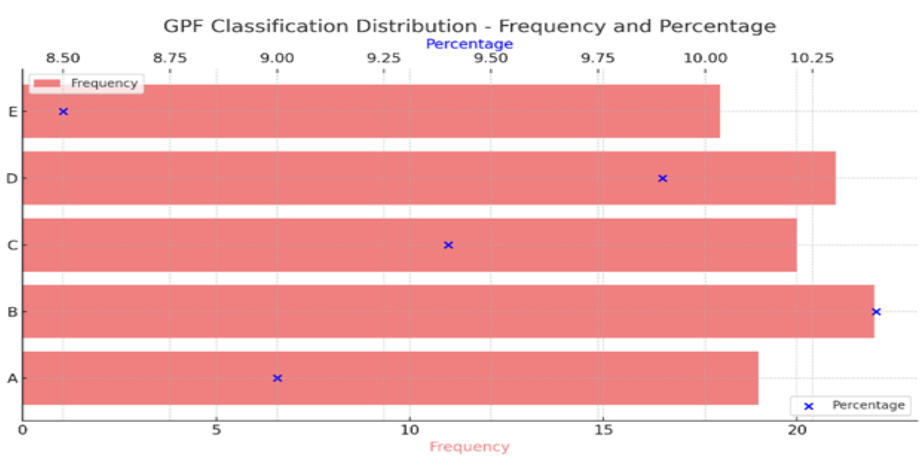

Figure 4 GPF Classification Distribution – Frequency and Percentage

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DISCUSSION

The present study examined the anatomical variation of the greater palatine foramen (GPF) among residents of Karachi using cone-beam computed tomography (CBCT), focusing on its morphometry and topographical relationship with key craniofacial landmarks including the median palatine suture (MPS), anterior nasal spine (ANS), and maxillary molars. These measurements hold significant clinical value, particularly in maxillofacial procedures where precise localization is necessary for effective anesthesia and surgical safety (12–15). The findings revealed equal representation of both genders and quadrant sides, which is a strength of the study, as it minimizes sampling bias and ensures balanced comparisons. The age distribution of participants, with a mean of 44.71 years and a wide standard deviation, provided a diverse sample that reflects different age groups within the population. Such diversity is advantageous, as previous studies have suggested that age-related anatomical variations may influence GPF location and size (14,16). The mean distance from the GPF to the MPS was 15.5 mm, while the mean distance to the ANS was 26.31 mm. These findings are consistent with reported ranges in international studies and underscore the importance of precise spatial knowledge for procedures such as palatal nerve blocks. The mean diameter of 5.22 mm with minimal variation further reinforced the general consistency of the GPF size across individuals. This stability in foramen diameter aligns with prior literature that noted limited variation in GPF dimensions, which enhances predictability in clinical application (17,18).

The distribution of the GPF relative to maxillary molars, based on the Ajmani classification, highlighted notable variability within the local population. The most frequent locations were opposite the second and third molars, with smaller proportions found between molar intervals or distal to the third molar. These findings mirror those of earlier cadaveric and radiographic studies that also identified the second and third molar regions as the most common positions of the GPF (19,20). Such variability confirms the inadequacy of relying solely on traditional textbook descriptions and emphasizes the need for population-specific anatomical data.

The statistical analyses demonstrated significant gender and quadrant differences in GPF dimensions and spatial orientation. The larger distances and diameters observed in males corroborate previously documented sexual dimorphism in craniofacial structures (21,22). Similarly, the variation between left and right quadrants adds to the growing body of evidence that anatomical symmetry cannot be assumed in clinical practice. These differences have direct clinical implications, as they indicate the necessity of individualized assessment during interventions involving the hard palate, particularly for nerve block administration and surgical procedures (23,24). From a clinical standpoint, these results reinforce the critical importance of accurate localization of the GPF to prevent complications such as hematoma, nerve damage, or anesthetic failure. The recognition of gender- and quadrant-based disparities in GPF location and size further supports the argument for tailoring surgical and anesthetic protocols to individual patients. These findings are especially relevant to procedures including cleft palate repair, periodontal surgeries, and pterygopalatine ganglion stimulation, where precision can directly influence success rates and patient outcomes (24). Similar to advancements in therapeutic dentistry, such as the use of silver nanoparticles in periodontal treatment to enhance safety and outcomes (25), the application of CBCT-based morphometric data supports more precise and effective surgical planning.

A notable strength of the study lies in its use of CBCT imaging, which offers sub-millimeter resolution and lower radiation exposure compared to conventional CT, thereby providing highly reliable morphometric data. The equal distribution of demographic factors further adds robustness to the comparisons performed. However, certain limitations must be acknowledged. The use of non-probability convenience sampling may restrict the generalizability of the findings to the broader Karachi population. Additionally, while the study focused exclusively on ethnic Karachiite individuals, further stratification by sub-ethnic groups was not performed, which could have provided deeper insights into intra-population variability. The cross-sectional nature of the study also limited its ability to assess changes in GPF dimensions across different age groups longitudinally. Future research should expand on these findings by employing probability-based sampling methods and larger multicenter samples to enhance generalizability. Comparative studies across different South Asian populations would also be valuable in establishing broader normative data. Furthermore, longitudinal designs investigating age-related changes in GPF morphometry and advanced volumetric analyses of the foramen could provide additional clinical insights. In conclusion, the study confirmed significant variation in the spatial orientation and morphometry of the GPF in a Karachi population, with clear gender- and quadrant-related differences. The findings provide clinically relevant normative values that may guide safer and more effective anesthetic and surgical interventions, while also contributing to the global body of craniofacial morphometric data.

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CONCLUSION

The present study concluded that the greater palatine foramen exhibits considerable anatomical variability in its spatial orientation and morphometry, underscoring the importance of population-specific data for clinical practice. By establishing localized normative values, the research contributes significantly to enhancing the precision and safety of maxillofacial procedures such as nerve blocks, palatal surgeries, and other interventions involving the hard palate. The findings emphasize the relevance of accurate anatomical knowledge in reducing iatrogenic risks and improving treatment outcomes. This work not only addresses a notable gap in the literature regarding South Asian populations but also lays a foundation for future research aimed at validating and expanding these insights across broader ethnic and geographical groups.

AUTHOR CONTRIBUTION

Author	Contribution
Mairaj Qasim*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Anwar Ali	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
More	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Saif Aslam Khan	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Farwa Waqar	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Usman Ghani Anwar	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published

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