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CBCT assessment of infraorbital foramen for maxillary sinus procedures: a cross-sectional variation according to age and gender in a Lahore-based Pakistani population

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ABSTRACT

BACKGROUND & OBJECTIVE: The infraorbital foramen (IOF) serves as a critical anatomical landmark for maxillofacial surgeries and nerve blocks. Its location is traditionally aligned with the maxillary second premolar, which may vary, potentially affecting surgical outcomes. This study aims to determine the location of IOF relative to various local anatomical reference points and to analyze variations across gender and age groups in the Lahore-based Pakistani Punjabi sub-population.

METHODOLOGY: Eighty-one CBCT scans, without maxillary pathologies, were analyzed. Distances were measured from IOF to the buccal cusp of the second premolar (IOF-PM), alveolar crest (IOF-AC), mid-maxillary line (IOF-MML), and lateral nasal wall (IOF-LNW). Data were stratified by gender and age groups, and statistical significance was assessed by comparing them between the two sides.

RESULTS: Significant asymmetry was observed only in the IOF-LNW distance, with right and left measurements of 12.90 ± 2.64 mm and 11.91 ± 2.64 mm, respectively. Males showed significantly greater IOF-PM and IOF-AC distances bilaterally than females ($p \leq 0.001$), while IOF-MML differed significantly by gender on the left Side only ($p = 0.008$). Age-related differences were significant for IOF-PM bilaterally (right $p = 0.047$; left $p = 0.007$), IOF-MML on the right Side ($p = 0.034$), and IOF-AC on the left Side ($p = 0.022$).

CONCLUSION: The IOF position demonstrates variations in side asymmetry, gender, and age. Understanding these differences enhances clinical precision for Pakistani Punjabi demographics, aiding in surgical planning for various maxillofacial surgeries and reducing iatrogenic risks.

KEYWORDS: Cone-Beam Computed Tomography, Gender Differences, Infraorbital Foramen, Maxillary Sinus, Radiography, Reference Values.

INTRODUCTION

The infraorbital foramen (IOF) is an essential landmark located on the maxillary bone approximately 1 cm inferior to the infraorbital margin^[1]. As the name suggests, the IOF serves as a passageway for the infraorbital nerve (ION) and associated blood vessels. ION is a purely sensory branch of the second branch of the trigeminal nerve (maxillary) which traverses the inferior orbital fissure into the inferior orbital canal and emerges on the face at the IOF^[2]. After emerging from the IOF, the ION further divides into branches that innervate the overlying skin and the mucous membrane of the midface, including the lower eyelid, cheek, lateral aspect of the nose, upper lip, and the labial gum^[3].

Traditionally, the IOF is believed to align with the second premolar, a reference point surgeons commonly use during clinical procedures^[4]. However, studies suggest that this alignment may not be consistent, suggesting the possibility that the IOF's location could vary, which warrants further investigation^[5].

The location of the IOF is crucial during invasive oral and maxillofacial surgeries, such as administering an ION block for regional anaesthesia, managing postoperative pain, and treating trigeminal neuralgia^[6]. Moreover, knowing the exact location prevents the risk of iatrogenic injuries to the ION in surgical procedures such as zygomatic region fractures, Le Fort type-I osteotomy, orbital floor reduction, and tumour surgery^[7-9]. The literature indicates that the IOF's

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location may vary across ethnic groups^[10]. Understanding these distances is crucial for surgical procedures involving the maxillary region, particularly for anesthetic blocks and maxillofacial surgeries^[11].

Identifying the exact position of the IOF can be challenging because it cannot be reliably detected by visual observation or physical examination alone. Therefore, specific techniques, including radiographic methods such as Orthopantomogram (OPG) and Cone Beam Computed Tomography (CBCT), as well as the analysis of dried human skulls, are employed^[12]. While much of existing research has relied on dry skull analysis, the use of CBCT provides a more accurate and noninvasive alternative for studying living subjects. Unlike dry cadaver studies, which lack real-time tissue context, CBCT allows precise anatomical localization in living patients. With advances of modern technology and successful clinical applications, CBCT has become increasingly prevalent because it offers higher resolution and greater accuracy in localizing anatomical structures than OPG or conventional radiographic methods^[11]. Additionally, CBCT offers less distortion in radiographic findings and less exposure time, thus reducing the radiation to the patient^[13].

Given the scarcity of studies on the Pakistani population using CBCT radiographs, it is essential to consolidate information specific to our ethnic group. As with other anatomical structures, differences in the exact position of anatomical landmarks can be influenced by a multitude of factors such as ethnicity, gender, or age. Such variation may hinder the effectiveness of local anaesthesia during surgical procedures or affect the clinical approaches used in the area. Previous studies have determined the IOF's location using CBCT radiography on dry human skulls, indicating a notable gap in focusing on the subcontinent, particularly the Pakistani Punjabi sub-population.

Establishing a reference for the location of the IOF within the Pakistani population by examining its clinical relationship to various anatomical landmarks- the buccal cusp of the second premolar (IOF-PM), the buccal Side of the alveolar crest of the second premolar (IOF-AC), the mid-maxillary line (IOF-MML), and the lateral nasal wall (IOF-LNW) will aid in treatment planning and enhance surgical outcomes. This study investigates the anatomical position of the infraorbital foramen (IOF) relative to defined craniofacial reference points. It evaluates its variations by sex and age within the Pakistani Punjabi sub-population.

METHODOLOGY

Ethical clearance for this retrospective study was obtained from the Ethical Review Committee of the University College of Dentistry, The University of Lahore, with reference number UCD/ERCA/24/342, approved on 24-04-2024. The CBCT scans used for this study were taken from the Department of Oral Radiology, University College of Dentistry, The University of Lahore, spanning the years July 2022 to June 2024. The sample size calculation was done with the help of the sample size determination in the Health Studies Calculator (Estimating the population mean). We calculated a sample size of 81 with an 80% confidence level, 4.92% absolute precision, and an expected mean distance from IOF to LNW of 11.96 ± 3.45 ^[3].

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All scans were performed using Planmeca Romexis software under specific parameters, including 5.6 mA, 90 k, a voxel size of 400 micrometres, an image size of 23.0×27.6 cm ($576 \times 576 \times 689$), and a 12-second scan time. These scans were processed and examined using Planmeca Promax software under consistent conditions, with adjustments for lighting and opacity to ensure clear visualization.

A purposive sampling technique was employed, focusing on selecting only those CBCT scans that depicted the anatomy of the maxillary region without any pathologies of abnormalities. We selected CBCT scans based on predefined inclusion and exclusion criteria. Scans were included if they demonstrated intact maxillary anatomy with a clearly visible infraorbital foramen and the presence of the maxillary second premolar, along with adequate image quality for precise measurements. Scans were excluded if they showed any maxillary pathology, craniofacial syndromes, cleft lip or palate, absence of the maxillary second premolar, or any technical errors such as motion artifacts, improper patient positioning, or reconstruction distortions that could compromise measurement accuracy.

The scans were analyzed in the coronal plane, especially at the point where the maxillary second premolar first became visible. Once the Infraorbital foramen appeared, its maximum horizontal width was measured at its widest point, and the midpoint was determined. From the midpoint, the following horizontal distances were measured to specific anatomical landmarks bilaterally. The midpoint of the infraorbital foramen was identified as the centre of its maximum horizontal diameter on the coronal slice where the foramen was best visualized. IOF-PM was defined as the linear distance from the IOF midpoint to the buccal cusp tip of the maxillary second premolar. IOF-AC was defined as the distance from the IOF midpoint to the buccal alveolar crest overlying the maxillary second premolar. IOF-MML was defined as the distance from the IOF midpoint to the mid-maxillary line passing through the mid-sagittal maxillary reference plane. IOF-LNW was defined as the distance from the IOF midpoint to the most lateral radiographically identifiable point of the nasal wall (Figure-I).

IOF to buccal cusp of maxillary second premolar (IOF-PM)
IOF to buccal Side of alveolar crest of the maxillary second premolar (IOF-AC)

IOF to mid-maxillary line (IOF-MML)

IOF to the lateral nasal wall. (IOF-LNW)

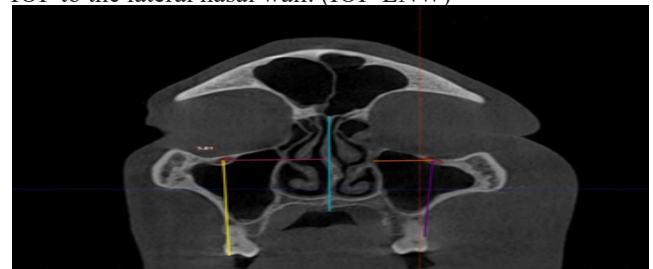


Figure-I: CBCT-based measurements of the infraorbital foramen. a) Maximum horizontal diameter of the infraorbital foramen (Red), b) Distance between IOF and buccal cusp tip of second PM (Yellow), c) Distance between IOF and alveolar crest (Purple), d) Distance between IOF and lateral nasal wall (Pink), e) Distance between IOF and mid maxillary line (Orange)

Infraorbital foramen on CBCT in Pakistan Punjab

We selected these reference points for their clear identification and reproducibility on CBCT scans. In particular, the distance from the IOF to the buccal cusp of the maxillary second premolar provides a standard reference for surgeons performing ION blocks.

To minimize inter-observer variability, all the radiographs were analyzed by the same examiner over a two-month interval. The examiner was pre-calibrated for CBCT software and trained to identify anatomical landmarks according to the specified inclusion criteria.

An intra-examiner reliability test was also conducted with a senior consultant reviewing the distance between the IOF and selected reference points. The intraclass correlation coefficient (ICC) values demonstrated excellent reliability across all measurements, ranging from 0.969 to 0.999 for both the left and right sides. The 95% confidence intervals were narrow and statistically significant, indicating strong consistency in the measurements obtained.

Electronic measurements of IOF distances were performed using the Planmeca Romeis software. The software's built-in measurement tools enabled precise calculation of distances between the IOF and selected anatomical landmarks. These measurements were categorized in terms of right and left IOF for each CBCT (162 foramina in total), along with gender and age. Age was divided into subgroups of ≤ 15 years, 16-25 years, 26-40 years, and above 40 years to account for skull growth variations. Age groups were defined to reflect developmental and adult craniofacial stages, including early growth (≤ 15 years), late adolescence/young adulthood (16-25 years), mature adulthood (26-40 years), and older adulthood (>40 years).

Statistical analysis was conducted using SPSS v24. An independent t-test was performed to compare measurements between the right and left sides, while one-way ANOVA was used to analyze differences among age groups. A p-value of ≤ 0.05 was considered statistically significant.

RESULTS

Table-I: Comparison of IOF measurements to anatomical landmarks on the right and left sides (mm).

Measurements	Mean $\pm$ SD		Min-Max		P-Value
	Right	Left	Right	Left	
	n=81	n=81	n=81	n=81	
IOF	3.59 $\pm$.86	3.61 $\pm$.86	1.65-6.70	1.60-5.90	0.859
IOF-PM	42.01 $\pm$ 4.85	41.17 $\pm$ 4.34	30.89-53.31	32.01-52.08	0.247
IOF-AC	34.36 $\pm$ 4.37	33.35 $\pm$ 3.91	24.01-46.40	25.00-44.19	0.123
IOF-MML	27.69 $\pm$ 3.33	27.39 $\pm$ 2.71	10.20-34.80	22.00-35.80	0.524
IOF-LNW	12.90 $\pm$ 2.64	11.91 $\pm$ 2.64	7.60-22.02	4.40-17.85	0.018*

*Significant p-value

Table-II: Comparison of average distances measured from the location of IOF to anatomical landmarks for males and females (mm).

	Right Side		Left Side		P-Value	
	Male	Female	Male	Female		
	42	39	42	39		
IOF	3.59 $\pm$.86	3.61 $\pm$.86	1.65-6.70	1.60-5.90	0.859	
IOF-PM	42.01 $\pm$ 4.85	41.17 $\pm$ 4.34	30.89-53.31	32.01-52.08	0.247	
IOF-AC	34.36 $\pm$ 4.37	33.35 $\pm$ 3.91	24.01-46.40	25.00-44.19	0.123	
IOF-MML	27.69 $\pm$ 3.33	27.39 $\pm$ 2.71	10.20-34.80	22.00-35.80	0.524	
IOF-LNW	12.90 $\pm$ 2.64	11.91 $\pm$ 2.64	7.60-22.02	4.40-17.85	0.018*	

*Statistically significant p-value

Among the distances measured between the IOF and the anatomical landmarks on the right and left sides, only IOF-LNW showed statistical significance. The average distance on the right Side was 12.90 $\pm$ 2.64 mm, and on the left Side, 11.91 $\pm$ 2.64 mm, with a significant p-value of 0.018 (Table-I). Although most measured distances showed no variation between sides, except IOF-LNW, which suggested some asymmetry, we will discuss differences between left- and right-side variables.

When analyzing the effect of gender on the measurements, a significant difference was observed in IOF-PM and IOF-AC

measurements between males and females on both sides. For instance, the IOF-PM distance on the right Side for males was 43.91 $\pm$ 4.77 mm, while for females it was 39.96 $\pm$ 4.09 mm, both with a p-value of less than 0.001 (Table-II).

Additionally, the IOF-MML distance showed a significant gender difference only on the left Side, with the male Side measuring 28.14 $\pm$ 2.58 mm and the female Side measuring 26.56 $\pm$ 2.61 mm (p of 0.008; Table-II). These findings suggest that gender impacts certain IOF-related measurements, with male distances being slightly higher than the female values.

Table-III: Comparison of average distances measured from the location of IOF to anatomical landmarks across various age groups on the right Side (mm).

Right Side (n=81)						
Age Group	n	IOF	IOF-PM	IOF-AC	IOF-MML	IOF-LNW
		Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD
≤ 15 Years	11	3.23 $\pm$ 0.42	38.29 $\pm$ 4.53	31.22 $\pm$ 4.29	25.44 $\pm$ 5.34	11.83 $\pm$ 2.05
16-25 Years	33	3.59 $\pm$ 1.03	42.28 $\pm$ 5.03	34.90 $\pm$ 4.84	28.24 $\pm$ 3.17	13.43 $\pm$ 2.65
26-40 Years	24	3.66 $\pm$ 0.74	42.68 $\pm$ 4.54	34.77 $\pm$ 3.69	27.24 $\pm$ 2.11	12.36 $\pm$ 2.17
>40 Years	13	3.75 $\pm$ 0.84	43.21 $\pm$ 4.21	34.91 $\pm$ 3.59	29.05 $\pm$ 2.65	13.47 $\pm$ 3.53
P-value		0.480	0.047*	0.083	0.034*	0.192

*Statistically significant p-value

Table-IV: Comparison of average distances measured from the location of IOF to anatomical landmarks across various age groups on the left Side (mm).

Left Side (n=81)						
Age Group	n	IOF	IOF-PM	IOF-AC	IOF-MML	IOF-LNW
		Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD
≤ 15 Years	11	3.18 $\pm$ 0.79	37.05 $\pm$ 2.98	30.03 $\pm$ 3.0	28.20 $\pm$ 3.59	12.29 $\pm$ 2.39
16-25 Years	33	3.58 $\pm$ 0.81	41.58 $\pm$ 4.21	33.85 $\pm$ 3.82	27.32 $\pm$ 2.68	12.37 $\pm$ 2.92
26-40 Years	24	3.73 $\pm$ 0.90	41.85 $\pm$ 4.40	33.67 $\pm$ 3.72	26.43 $\pm$ 1.97	10.86 $\pm$ 2.11
>40 Years	13	3.82 $\pm$ 0.88	42.31 $\pm$ 3.92	34.27 $\pm$ 4.08	28.60 $\pm$ 2.70	12.31 $\pm$ 2.65
P-value		0.252	0.007*	0.022*	0.082	0.149

*Statistically significant p-value

Age also impacts certain IOF measurements, though the differences were not consistent across all parameters. Age-group comparisons showed significant differences in IOF-PM on both sides (right $p=0.047$; left $p=0.007$), IOF-MML on the right Side ($p=0.034$), and IOF-AC on the left Side ($p=0.022$). Mean IOF-PM and IOF-AC values were lower in the youngest age group and higher in older age groups. (Table-III and IV).

To summarize, the IOF-LNW measurement showed significant asymmetry between the left and right sides. Gender differences were evident in IOF-PM and IOF-AC on both sides and in IOF-MML on the left Side. Age had a significant effect on IOF-PM on both sides, IOF-MML on the right Side, and IOF-AC on the left Side.

DISCUSSION

The location of the IOF is crucial information for its sensory innervation and for providing regional anesthesia. Understanding these distances matters for various surgical procedures involving the maxillary region, particularly anesthetic blocks and maxillofacial surgery^[11,6]. Comparing IOF locations across ethnicities can inform necessary surgical adjustments. Additionally, radiographs offer a minimally invasive method to determine the location of IOF, providing an accurate and precise representation of anatomical structures. Therefore, using CBCT to obtain the measurements is a vital tool moving forward.

Regarding the average horizontal diameter of the foramen, this study showed the measurement for males to be 3.64 $\pm$ 0.97 mm, which is slightly higher when compared to females. A study conducted in Turkey reported a mean distance of 3.17 $\pm$ 0.56 mm, while another study conducted in Iran recorded a value of 3.54 $\pm$ 0.54 mm^[14,15]. A study conducted in India

found an average horizontal diameter of 3.16 $\pm$ 0.96 mm. However, a study conducted in central Africa reported a mean transverse diameter of the IOF of 1.97 mm $\pm$ 0.51 on the left and 1.78 mm $\pm$ 0.53 on the right, showing variation across ethnicities^[10]. These results indicate an overall trend: the actual size of the foramen does not differ significantly across gender, ethnicity, or Side. While other studies have highlighted variations in the shape of the foramen, these findings focus on diameter, suggesting consistency in these measurements across groups^[16]. On the contrary, a study of human skulls from the African population reported a transverse diameter of 2.7 $\pm$ 0.61 on the left Side and an average of 2.8 $\pm$ 0.48 in the Caucasian population^[10].

The IOF-PM distance on the male right Side was 43.91 $\pm$ 4.77 mm, while the corresponding female distance was 39.96 $\pm$ 4.09 mm, both with a p-value of less than 0.001. These values aligned with a study conducted in India, in which the mean distance from the IOF to the occlusal plane of the maxillary second premolar was 39.02 $\pm$ 2.65 mm on the right Side and 39.49 $\pm$ 2.53 mm on the left Side^[1]. However, in cadaveric studies, this distance changes to 27.11 $\pm$ 5.16 mm and 26.71 $\pm$ 5 mm on the left Side^[17]. These findings indicate that gender-specific anatomical variations must be considered when assessing IOF-OM distances, as male values are consistently measured higher than female values across various studies.

This study also reported mean distances from IOF to the mesial alveolar crest over the maxillary second premolar (IOF-AC) at 34.36 $\pm$ 4.37 mm on the right Side and 33.35 $\pm$ 3.91mm on the left Side, both values falling slightly higher than those reported in India, where the distances measured were 32.64 $\pm$ 2.67 mm on the right Side and 31.64 $\pm$ 2.33 mm on the left Side^[1]. Another study on cadavers

in India by Mahajan et al. reported that the distance of the infraorbital foramen from the alveolar margin is 29.6 mm on the right and 29 mm on the left^[5]. Similarly, a study in the Sri Lankan population reported these measurements as 29.59 ± 3.59 mm on the right and 29.65 ± 3.28 mm on the left^[3]. Other studies from the South Indian population reported lower values of less than 28mm^[18,19].

Furthermore, the distance between the mid-maxillary line and IOF in the present study is consistent with findings from studies conducted in India and Iran, the latter of which reported an average distance of 25.10 ± 2.17 mm^[16,15]. The study values were approximately 3.21 mm higher than this, which aligns with the trend that the majority of the values in their study are lower than those reported in this study. Additionally, a study of the Lebanese population reported a slightly smaller mean difference between the IOF and the midline, at 24.71 ± 2.09 mm^[20]. In the Sri Lankan population, this is around 27.13 ± 2.6 and 26.99 ± 2.73 on the right and left sides, respectively^[3].

When examining the difference between the IOF and LNW, the present study results on the left Side were nearly identical to those reported in a study conducted in Sri Lanka, with a value of 11.92 ± 2.89 mm for females on the left Side^[3]. The measurements for males were 12.19 ± 2.64 mm, while the Sri Lankan study reported an average of 12.44 ± 2.74 mm, indicating a strong correlation^[3]. The majority of their values closely aligned with those of the present study, suggesting that regional similarities influence IOF location. However, a notably lower value was recorded in the study from Iran, where the distance from IOF to LNW was 9.32 ± 2.68 mm; this difference can also arise from differences in measurement methods across studies in terms of reference points used when taking the final measurements.¹⁵ Similarly, a study in Lebanon reported an average of 10.61 ± 2.39 mm, which falls between this study and the Sri Lankan findings but remains higher than those from Iran^[20].

Our study highlights the significance of age-related variations in the distances from IOF to various anatomical landmarks, which is important for surgical interventions and regional blocks. Studies show that the vertical and horizontal dimensions of the IOF can change, with older individuals often exhibiting larger foramina due to bone remodelling^[21]. Our study indicates a statistically significant increase in the mean distance from the IOF-PM with age, as evidenced by measurements on the right Side, where individuals over 40 years showed a mean distance of 43.21 ± 4.21 compared to 42.28 ± 5.03 in those aged 16-25 years. This trend is consistent with previous studies; for instance, research on Indian skulls reported that the mean distance from the infraorbital margins to the IOF increased with age, averaging 6.12mm on the right Side and 6.19mm on the left Side^[12]. Similarly, Brazilian skulls showed sagittal distances of 6.71mm on the right and 6.83 mm on the left, further indicating a consistent pattern of increasing dimensions with age^[22]. Osbon et al. noted that as individuals age, the overall morphology of the orbital region, including IOF, tends to enlarge^[23]. However, a recent study from northern India by Desai et al. found no significant differences in mean values between genders and age groups^[1].

This discussion highlights that even slight variations in distances from the IOF may reflect ethnic differences in anatomical structures. In critical anatomical procedures, particularly those requiring precise knowledge of the location of the ION for nerve blocks, it is essential for oral surgeons to consider these differences while operating on specific populations.

As of limitation, this study's findings are based on data collected from a single hospital in Lahore, Pakistan, and may not represent the broader region. To develop a standardized approach to locating the IOF, it is important to collect more comprehensive data from multiple hospitals. Furthermore, comparisons are challenging due to variations in the reference points used for measurements, which may differ depending on the preferred techniques of individual oral surgeons for performing IOF blocks or related surgical procedures.

CONCLUSION

The present study demonstrated that IOF-LNW exhibited significant side asymmetry, whereas IOF-PM and IOF-AC distances were significantly greater in males than in females. Age-related variation was primarily observed in IOF-PM measurements, indicating a gradual positional shift of the infraorbital foramen relative to dentoalveolar landmarks. These findings suggest that reliance on fixed anatomical assumptions may be inadequate and highlight the importance of individualized radiographic assessment before maxillofacial procedures. However, as the data were derived from a single-centre retrospective sample, broader generalization should be approached with caution.

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