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Anatomical interrelationship between infraorbital canal and maxillary sinus: a CBCT-driven exploratory study

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SUMMARY

The anatomical relationship between the infraorbital canal (IOC) and the maxillary sinus (MS) is of critical importance in maxillofacial surgery, implantology, and endodontics. This exploratory study aims to investigate this relationship using cone-beam computed tomography (CBCT) imaging to provide precise anatomical insights. A retrospective analysis was conducted on CBCT scans of 174 patients, evaluating the positional variations, distances, and morphological characteristics of the Infraorbital canal in relation to the Maxillary Sinus. The results demonstrated significant variations in the proximity and spatial orientation of the infraorbital canal and maxillary sinus, highlighting the necessity for careful preoperative planning to avoid complications during surgical interventions. This study underscores the value of CBCT in enhancing the understanding of maxillofacial anatomy, thereby improving clinical outcomes and patient safety in procedures involving the maxillary region.

Key words: Maxillary sinus – Cone Beam Computed Tomography – Infraorbital – Morphometry

INTRODUCTION

The infraorbital groove, located on the posterior aspect of the orbital surface of the maxilla, marks the beginning of the infraorbital canal. This groove serves as the initial pathway for the infraorbital nerve and vessels. The groove undergoes a transition into the infraorbital canal, which runs forward and slightly downward within the maxilla. Bone encases the canal, providing a protective passage for its contents. The canal terminates at the infraorbital foramen, an opening located approximately 1 cm below the infraorbital margin, which is the exit point for the infraorbital nerve and vessels onto the face.

The infraorbital nerve, a branch of the maxillary division (V2) of the trigeminal nerve (cranial nerve V), provides sensory innervation to the lower eyelid, side of the nose, upper lip, and upper cheek. The infraorbital artery, a branch of the maxillary artery, supplies blood to the lower eyelid, upper lip, and cheek. The infraorbital vein runs alongside the artery and nerve, draining blood from these regions. These structures are crucial for sensory perception and blood flow to the midfacial region, and any harm to them might lead to numbness, discomfort, or vascular issues.

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The infraorbital foramen serves as a critical surgical landmark in various procedures, including local anaesthesia administration (infraorbital nerve block), maxillofacial surgeries, and cosmetic interventions. Due to the proximity of the infraorbital canal to the maxillary sinus, sinus surgeries must carefully account for its location to prevent nerve damage. Additionally, understanding the position of the infraorbital canal is essential in dental implant placement and other maxillary surgeries to avoid complications.

Anatomical variations can occur in the exact location and course of the infraorbital canal between the left and right sides of the same individual, as well as between different individuals. Some individuals may have a more superficial canal, while others may have a canal that protrudes more into the maxillary sinus. Such variations can be assessed through various imaging techniques. Among them is the more promising and advanced technique of cone beam computed tomography (CBCT).

Cone beam computed tomography (CBCT) allows for high-resolution, three-dimensional visualisation of both bone and soft tissues in the maxillofacial region. This enables clinicians to accurately assess the position and morphology of the infraorbital canal, the infraorbital foramen, and its protrusion into the maxillary sinus. It is decisive in precise preoperative planning by providing detailed information about the anatomical variations. Surgeons can utilise this crucial information to develop a customised surgical approach that minimises the chances of intraoperative challenges and complications, while still achieving outstanding postoperative success.

MATERIALS AND METHODS

The study sample consisted of 174 subjects, comprising males and females from the southern Karnataka population. The study was conducted in a monocentric setting as a descriptive retrospective study. Strict inclusion and exclusion criteria were followed to ensure the anatomical integrity, necessary for studying the infraorbital canal protrusion into the maxillary sinus. All subjects were ethically sourced and prepared, with proper adherence to ethical guidelines.

Inclusion Criteria

- CBCT images with optimum diagnostic quality
- CBCT scans that indubitably display the structure of the skull especially the sinonasal complex

Exclusion criteria

- Image with the presence of any developmental anomaly/ central pathology involving the maxilla-orbital complex.
- Image with any evidence of previous surgery, fracture, or healed fracture of the maxilla-orbital complex.
- Nondiagnostic CBCT images, including partial images or the presence of artefacts in the maxilla-orbital complex.

Methodology

The archaic CBCT images satisfying the inclusion and exclusion criteria were procured from the Department of Oral Medicine and Radiology. CBCT image analysis was done in axial, coronal, and sagittal sections using Planmeca romexis 5.3(3D software) for the following:

Based on the classification made by Ference et al (Ference et al., 2015), the infraorbital canal (IC) was divided into 3 types according to the degree of protrusion (Fig. 1):

- Type 1 – The IC is located entirely within the roof of the maxillary sinus.
- Type 2 – The IC is located under the roof of the sinus, but remains adjacent to it.
- Type 3 – The IC descends into the sinus lumen, suspended from the sinus roof within a septa or lamella of the infraorbital ethmoid cell.

Linear Measurements

- Horizontal Diameter: Width of the foramen when measured from side to side. (Fig. 2A)
- Vertical Diameter: Height of the foramen from its superior (upper) to inferior (lower) border (Fig. 2B)
- Infraorbital Canal to Canine Root: The linear measurement from the midpoint of the infraorbital foramen to the apex of the canine root (Fig. 2C)

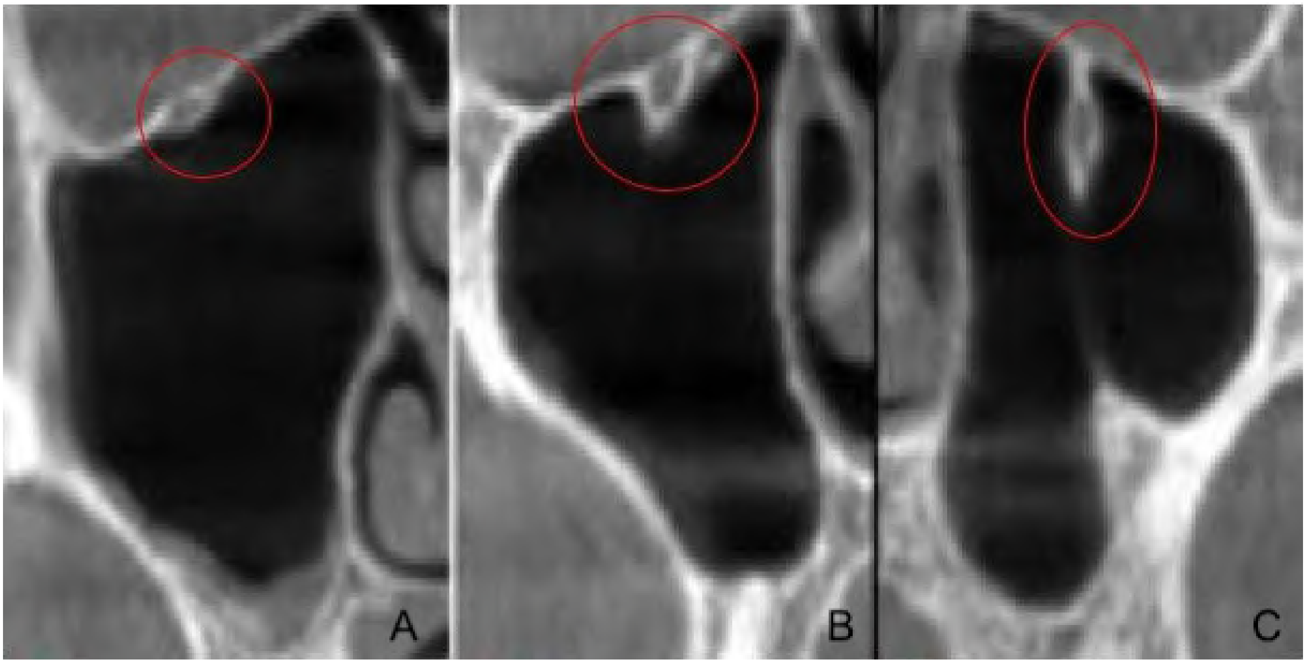

Fig. 1.- Coronal section scans of type 1 (**A**) and Type 2 (**B**) and Type 3 (**C**).

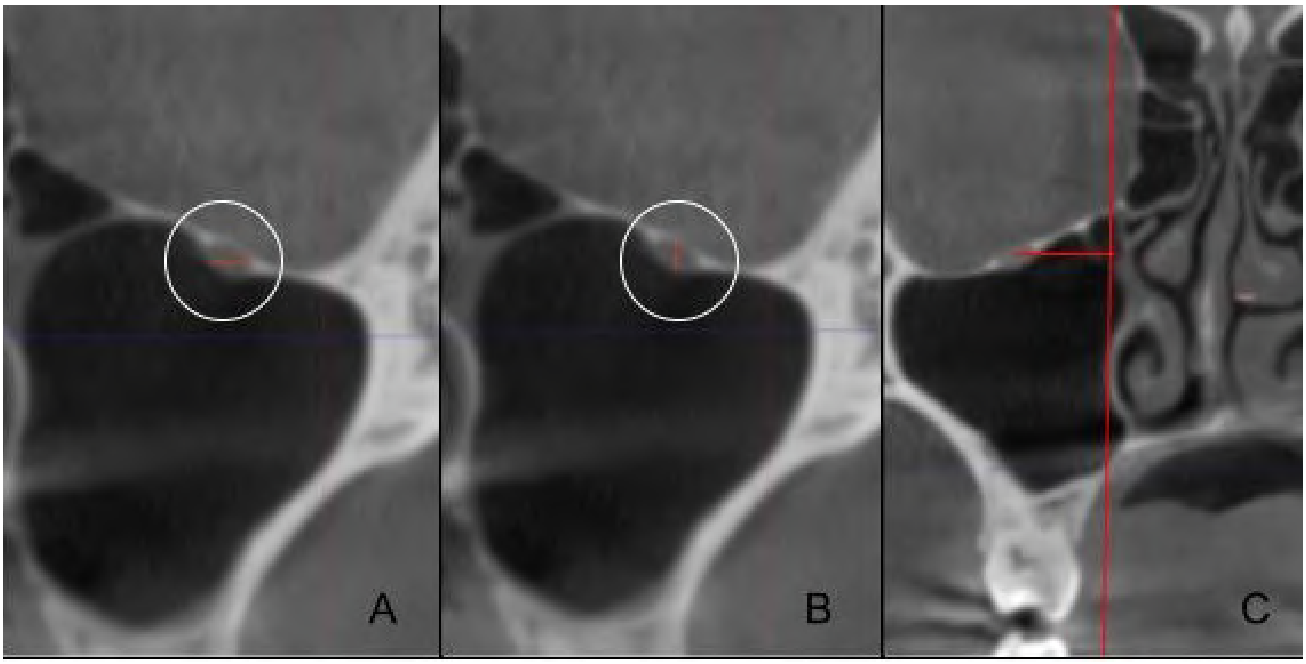

Fig. 2.- A- Horizontal diameter; **B**- Vertical Diameter; **C**- Distance between the infraorbital foramen and the canine root.

Statistical Analysis

The descriptive analysis included evaluating categorical variables as numbers and percentages, as well as calculating the mean and standard deviation values. The data were statistically evaluated using the Chi-Square test, with $p < 0.05$ considered statistically significant.

RESULTS

A total of 347 infraorbital canals (ICs) (174 right and 173 left) were analysed, out of which 191 were females and 156 were males. The ages of the patients ranged from 18 to 75 years of age. Tables 1 and 2 show descriptive data that were used to estimate mean, standard deviation, maximum,

Table 1. Descriptive data based on Sex.

Parameters	Sex	Mean	Std. Deviation	Minimum	Maximum
Horizontal Diameter (in mm)	Female	2.863	0.637	2.000	4.680
	Male	3.097	0.793	2.000	4.470
Vertical Diameter (in mm)	Female	2.829	0.691	1.440	4.000
	Male	2.799	0.719	1.440	4.000
IC-CR (in mm)	Female	18.201	3.118	12.010	25.610
	Male	18.494	3.257	12.020	25.610

Table 2. Descriptive data based on Side.

		Mean	Std. Deviation	Minimum	Maximum
Horizontal Diameter (in mm)	Left	2.969	0.722	2.000	4.680
	Right	2.968	0.720	2.000	4.680
Vertical Diameter (in mm)	Left	2.812	0.702	1.440	4.000
	Right	2.819	0.706	1.440	4.000
IC-CR (in mm)	Left	18.332	3.189	12.010	25.610
	Right	18.333	3.180	12.010	25.610

and minimum data based on sex and side. Figure 3 depicts the horizontal and vertical diameter of the canal based on sex and side. Fig. 4 and Table 3 depicts the IC-CR based upon sex and side.

Table 3. Type VS Sex/Side.

	Type	Female	Male
Sex	1	63	74
	2	124	82
	3	4	0
Side	1	68	69
	2	103	103
	3	2	2

The Independent Samples T-Test results reveal a significant sex-based difference in the horizontal diameter, with males having larger measurements (t = -3.059, df = 345, p = 0.002). However, no significant differences were found between males and females for the vertical diameter (t = 0.392, df = 345, p = 0.696) or the IC-CR (infraorbital canal to canine root) measurements (t = -0.854, df = 345, p = 0.394). When comparing the left and right sides of subjects, there were no significant differences in the horizontal diameter (t = 0.012, df = 345, p = 0.991), vertical diameter (t = -0.090, df = 345, p = 0.928), or IC-CR measurements (t = -0.001, df = 345, p = 0.999) (see Table 4). Thus, only the horizontal diameter shows a significant difference based on sex,

Table 4. Independent T-test.

	Parameters	t	df	p
Based on Sex	Horizontal Diameter (in mm)	-3.059	345	0.002
	Vertical Diameter (in mm)	0.392	345	0.696
	IC-CR (in mm)	-0.854	345	0.394
Based on Side	Horizontal Diameter (in mm)	0.012	345	0.991
	Vertical Diameter (in mm)	-0.090	345	0.928
	IC-CR (in mm)	-0.001	345	0.999

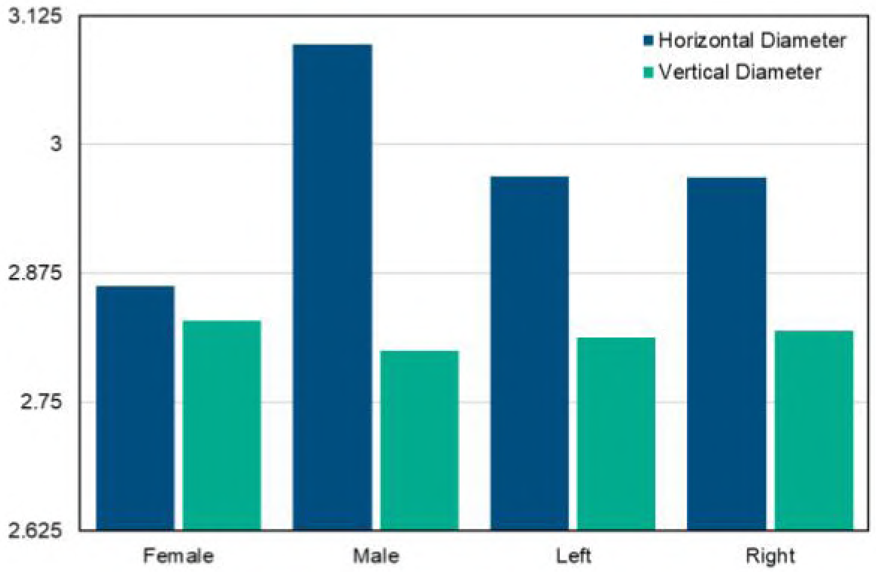

Fig. 3.- Comparison of horizontal and vertical diameter among sex and side.

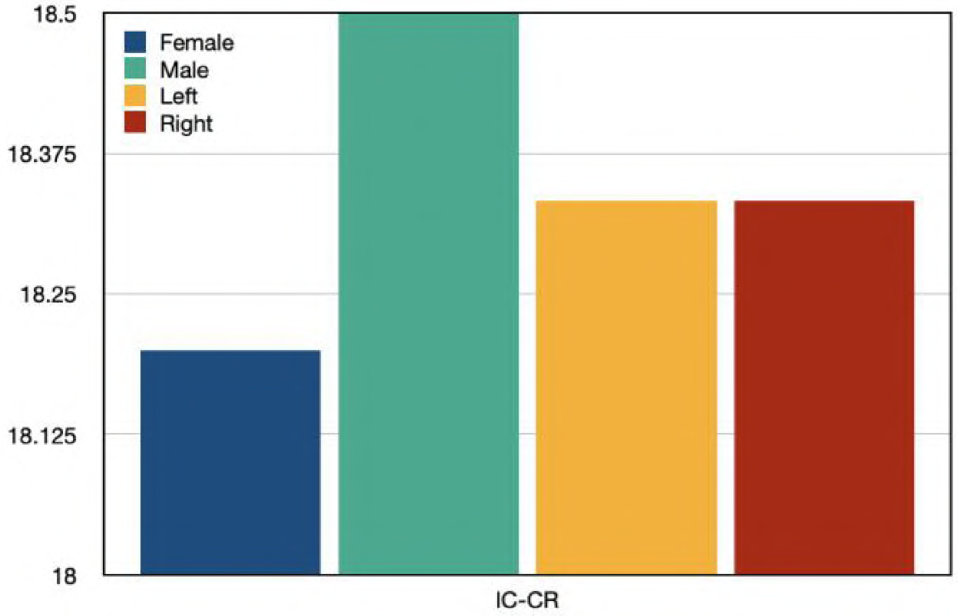

Fig. 4.- Comparison of IC-CR among sex and side.

while no significant differences were found based on side (left vs. right) for any of the measurements.

The Chi-squared tests analyse the distribution of canal types based on sex and side. For the distribution based on sex, the Chi-squared value is 10.018 with 2 degrees of freedom (df), and the p-value is 0.007. This indicates a statistically significant difference in the distribution of canal types between males and females, suggesting that sex has an impact on the type of canal. In contrast, for the distribution based on side, the Chi-squared value is 0.004 with 2 df, and the p-value is 0.998. This indicates no significant difference in the distribution of canal types between the left and right sides, suggesting that the side does not affect the type of canal. Overall, the type of canal is influenced by sex but not by side (Table 5 and Fig. 5).

Table 5. Chi-Squared Tests for Type of Canal.

	Value	df	p
Based on Sex	10.018	2	0.007
Based on Side	0.004	2	0.998

DISCUSSION

The infraorbital foramen's development and relationship with the maxillary sinus protrusion are subjects of considerable interest in the fields of anatomy, anthropology, and clinical medicine. The infraorbital foramen serves as a passageway for the infraorbital nerve, artery, and vein, which provide sensory and vascular supply to the lower eyelid, cheek, nose, and upper lip (Kazkayasi et al., 2003). Variations in the size, shape, and position of this foramen have been observed across different populations and have been linked to factors such as ancestry, environmental influences, and pathological conditions (Chrcanovic et al., 2011; Nanayakkara et al., 2016; Singh, 2011). Moreover, the proximity of the infraorbital foramen to the maxillary sinus, an air-filled cavity within the maxillary bone, raises questions about potential interrelationships between their respective morphologies and the implications for clinical practices involving the maxillofacial region.

The relationship between the infraorbital foramen and maxillary sinus protrusion holds significant implications in the field of dentistry and maxillofacial surgeries. In dental procedures involving the maxillary region, such as anaesthesia administration, implant placement, sinus lifting, or orthognathic surgeries, a thorough understanding of the infraorbital foramen's position and its proximity to the maxillary sinus is crucial. Any inadvertent damage or impingement on the infraorbital nerve during these procedures can lead to sensory disturbances, paresthesia, or even neurovascular complications in the innervated areas of the face (Smith, 1921).

Furthermore, the degree of maxillary sinus protrusion can influence the available bone volume for dental implant placement or other reconstructive procedures (Dutton, 2023). Excessive protrusion may necessitate modifications in surgical techniques or the use of advanced bone grafting methods to ensure adequate bone support and prevent potential complications. Maxillofacial surgeons must carefully evaluate the anatomical relationship between these structures preoperatively, often through detailed radiographic imaging, to plan surgical approaches that minimise risks and optimise functional and aesthetic outcomes for patients undergoing procedures in this intricate anatomical region.

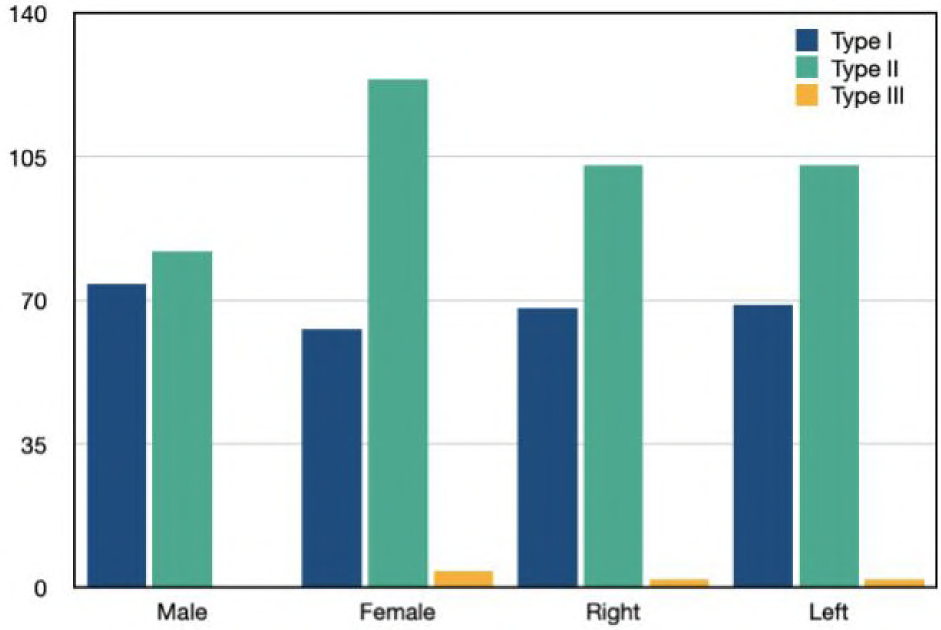

Fig. 5.- Comparison of horizontal and vertical diameter among sex and side.

In the present study, significant results were obtained between male and female for the horizontal diameter of the infraorbital foramen. A study conducted by Elsheikh et al., had similar findings among the adult Egyptian population (Elsheikh et al., 2013). Many other studies also supported the similar finding (Apinhasmit et al., 2006; Desai et al., 2012; Singh, 2011). These findings can be attributed to the population specificity, as well as to the larger skull dimensions of the males horizontally. The vertical diameter of the infraorbital foramen shows no significant differences in the current study, nor in the studies undertaken by different authors for different populations, as there is less sexual dimorphism of the skull foramina vertically; moreover, most of these dimensions are influenced by the supporting and adjacent structures of the skull (Desai et al., 2012; Ilayperuma et al., 2010; Junior et al., 2012; Macedo et al., 2017; Singh, 2011).

The horizontal and vertical diameter of the infraorbital foramen exhibits variations between the left and right sides, with some studies showing no significant differences and others indicating slight differences (Elsheikh et al., 2013; Gibelli et al., 2019; Mahajan et al., 2023; Singh, 2011). While one study found no significant differences (Elsheikh et al., 2013), another reported a slight difference, with a mean of 2.6 mm on the right side and 2.5 mm on the left side (Mahajan et al., 2023). The shape and size of the infraorbital foramen can vary significantly between individuals, with oval, round, and triangular shapes observed in different studies (Polo et al., 2019). Additionally, there is no significant difference in the horizontal and vertical diameter of the infraorbital foramen bilaterally, even in the current study.

The prevalence of infraorbital canal protrusion into the maxillary sinus was found to be approximately 10.8%, with bilateral protrusion occurring in about 5.6% of cases in a study conducted by Lantos et al., (Lantos et al., 2016). This anatomical variation can be classified into three types based on the extent of the canal's bulge into the sinus, with Type 1 exhibiting no protrusion, Type 2 showing extension beyond the sinus roof, and Type 3 demonstrating protrusion through the sinus wall (Kalabalık et al., 2020). These findings highlight the importance of recognizing this variation during sinus surgery to avoid potential injury to the infraorbital nerve.

On analysis of the type of canal based on sex and side, sex significantly influences the distribution of canal types, as evidenced by a Chi-squared value of 10.018 with 2 degrees of freedom and a p-value of 0.007, indicating a statistically significant difference between males and females. This suggests that sex is an important factor in determining canal type. In contrast, the distribution of canal types based on the side (left or right) shows no significant difference, with a Chi-squared value of 0.004, 2 degrees of freedom, and a p-value of 0.998, suggesting that the side does not affect canal type. Overall, while sex impacts the type of canal, the side does not. This is similar to the study conducted by Ference et al. (2015), Kalabalik et al. (2020), and Fontolliet et al. (2019).

The distance between the infraorbital canal and the maxillary canine root has been measured in various studies, with reported values ranging from around 8.5 mm to 12 mm (Haghnegahdar et al., 2018). The present study showed a mean of 18.347 with a range of 12 to 25 mm. These variations can be attributed to the difference in ethnicity and the sample selection criteria. These anatomical relationships are crucial to consider during surgical procedures in the maxillofacial region, as they can impact the success and safety of the operation in various populations. The current study showed no significant difference between sexes nor with any bilateral variations.

Iatrogenic injuries to the infraorbital foramen protruding into the maxillary sinus can occur during various surgical procedures involving the maxillofacial region, particularly functional endoscopic sinus surgery (FESS) and the Caldwell-Luc operation. During FESS, which aims to improve sinus drainage and ventilation, the close proximity of the infraorbital foramen to the maxillary sinus poses a risk of inadvertent trauma to the infraorbital nerve, leading to sensory disturbances or neuropathic pain in the distribution of the nerve (Schlosser and Harvey, 2012). Similarly, in the Caldwell-Luc procedure, which involves creating a window in the anterior wall of the maxillary sinus for access and treatment, improper identification or excessive manipulation of the infraorbital foramen region can result in nerve injury, bleeding, or potential communication between the sinus and the oral cavity (Majapuro, 1976).

In the context of standard functional endoscopic sinus surgery (FESS), the risk of iatrogenic injury to the infraorbital canal is minimal, owing to the precise visualization afforded by 30° or 45° endoscopic optics (Zanuncio et al., 2024). However, when pathology necessitates access to the pterygopalatine fossa, the potential for direct or indirect compromise of the infraorbital nerve at the foramen rotundum increases significantly (Tashi et al., 2016). Moreover, in cases of orbital pathology such as Graves-Basedow orbitopathy, the medial displacement of the infraorbital canal reduces the horizontal distance, thereby altering the surgical anatomy (Perros et al., 2017). This anatomical variation is particularly relevant in inferior orbital decompression procedures, where the infraorbital canal serves as the lateral boundary of surgical intervention (White et al., 2003). It is crucial to note that these scenarios transcend the scope of routine FESS, entering the realm of advanced endoscopic sinus surgery, which demands a higher level of expertise and carries increased potential for neurovascular complications. Meticulous preoperative planning, precise surgical technique, and a thorough understanding of the anatomical variations in the relationship between the infraorbital foramen and the maxillary sinus are paramount to minimising iatrogenic complications and ensuring favourable patient outcomes in these delicate surgical interventions.

This study's findings offer critical insights into predicting the specific locations and characteristics of the infraorbital foramen, particularly within the South Indian population. Understanding the precise distances from anatomical landmarks as outlined in this study can greatly aid surgeons in locating these essential maxillofacial structures. This knowledge can help prevent iatrogenic neurovascular bundle injuries and enhance the precision of surgical, local anaesthetic, and other invasive procedures.

CONCLUSION

Understanding the anatomy of the infraorbital foramen is crucial for a wide range of clinical applications. The variability in its position, size, and shape necessitates individualised assessment and careful preoperative planning to avoid complications. Advances in imaging technology and future research should continue to explore the prevalence and impact of this variation in orderto further refine surgical techniques and improve patient care.

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