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Morphometry of the three prominent facial foramina in a South African sample using Cone Beam Computed tomography scans

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ABSTRACT

Introduction

The supraorbital notch or foramen, infraorbital and mental foramina transmit sensory nerves commonly anaesthetised in aesthetic and dental procedures. Understanding variations in the location and size of these foramina is essential for safe and effective nerve blocks.

Aims and objectives

This study aimed to determine the mean anatomical location and shape of facial foramina in a South African sample.

Design and methods

Retrospective Cone Beam Computed Tomography (CBCT) scans of 159 South African adults (44 white females, 42 white males, 31 black females, 42 black males) were analysed using the MeVisLab © v.3.0.2 software. The facial foramina were classified by shape (round, oval, notch) while 15 three-dimensional landmarks were used to describe the location of these foramina.

Results

A supraorbital notch was observed in 74% of cases, while the infraorbital and mental foramina were predominantly round. No asymmetry in the location of the foramina was detected. The foramina were positioned further from the midline in males compared to females and in black South Africans compared to white South Africans. Sexual dimorphism in the location of the facial foramina was more pronounced in the white South African sample ($p < 0.01$).

Conclusion

These sex- and population-specific variations should be considered to enhance nerve block effectiveness and reduce the anaesthetic dose during aesthetic and dental procedures.

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Keywords

Aesthetic procedures, infraorbital foramen, mental foramen, population variation, sexual dimorphism, supraorbital foramen.

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Declaration of Interest

The authors declare that they have no competing interests to disclose

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INTRODUCTION

Surgeons rely on palpable skeletal landmarks to identify underlying structures and establish surgical approaches. Precise knowledge of these landmarks and their relationships is essential to minimise the risk of damage to critical neurovascular structures.[1] The supraorbital foramen (SOF) or notch (SON), infraorbital foramen (IOF) and mental foramen (MF) are essential skeletal landmarks which serve as passageways for neurovascular bundles traveling between internal and external cranial regions.[2] Clinicians commonly assume these foramina lie in a single sagittal plane, equidistant from the midline.[3] This assumption underpins surgical guidelines used for nerve blocks, allowing for approximate localization of the infraorbital and mental foramina by palpating the SOF/N.[1] However, research has indicated that the position, shape and size of these foramina exhibit significant variability, which is influenced by ontogeny, sex and population differences.[4-7] To prevent neurovascular damage during anaesthetic administration, these anatomical variations must be carefully considered.[8]

The SOF/N, IOF and MF are located on the anterior aspect of the face and transmit sensory nerves, originating from the divisions of the trigeminal nerve, and vascular structures that bear the same names as the openings.[9-10] The SOF/N is situated on the superomedial aspect of the orbital margin in the frontal bone, and allows the supraorbital nerve, a branch of the ophthalmic division of the trigeminal nerve, to exit and innervate the forehead, scalp, superior eyelid and frontal sinus.[9] The IOF, located in the maxilla just inferomedial to the infraorbital margin, transmits the infraorbital nerve, the terminal branch of the maxillary division of the trigeminal

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nerve.The infraorbital nerve supplies sensory innervation to the inferior eyelid, lateral aspect of the nose, upper lip and maxillary labial gingiva.[11] The MF, found on the anterolateral aspect of the mandibular body, serves as the exit point for the mental nerve, the branch of the inferior alveolar nerve that arose from the mandibular division of the trigeminal nerve. The MF is typically positioned between the roots of the mandibular premolars or apical to the second premolar.[1,11]

Studies conducted to determine the location of the facial foramina have shown contradicting results regarding sexual dimorphism.[1,2,4,10-13] Some research has reported significant differences between males and females,[2,4,12] while others found little to no variation,[1,13] suggesting potential population-specific sex differences. Agthong and co-workers. (2005)[2] reported that the infraorbital foramen was closer to the anterior nasal spine in females compared to males, and the position of the mental foramen varied between sides. Apinhasmit and colleagues (2006)[4] found that males exhibited greater distances from the facial foramina to their surrounding bony landmarks. Sexual dimorphism affected most measurements, except for the specific distances related to the supraorbital and infraorbital foramina, while asymmetry in the location of the mental foramen was reported.[4] Conversely, Lim and colleagues (2016)[13] found minimal sexual dimorphism in a Korean sample, with the only significant difference reported in the distance from the mental foramen to the inferior border of the mandible in males. Similarly, Hester et al. (2021)[1] reported no notable sex differences except for a slightly greater distance from the right infraorbital foramen to the midline in males. These findings highlight the variability in the position of the facial foramina and suggest the need for further research on population-specific sexual dimorphism.

In addition, interpopulation variation was noted in the position of the SOF/N, IOF and MF.[2,13] Research conducted on dry Kenyan skulls revealed that the average distances from the midline to the facial foramina were greater in Kenyans compared to other populations as the SOF/N was located 27.22 mm, the IOF 28.91 mm, and the MF 27.75 mm from the midline.[14] Comparison of these findings to a study conducted on dry Indian skulls revealed greater distances from the midline to the SOF/N and MF in Kenyans, while the IOF was located further from the midline in Indians.[5,14] While previous American surgical guidelines were based on the assumption that White Americans and Hispanics share comparable facial foramina locations, research by Hester et al. (2021)[1] contradicts this assumption. Their study, involving 67 skulls (28 females, 39 males), revealed a significant difference in the infraorbital foramen (IOF) position, with Hispanics exhibiting a greater distance from the midline.

Due to the noted variation in the literature and the lack of comparable data on South Africans, this study was undertaken to determine the size and location of the SOF/N, IOF and MF in contemporary black and white South African Cone Beam Computed Tomography (CBCT) sample.

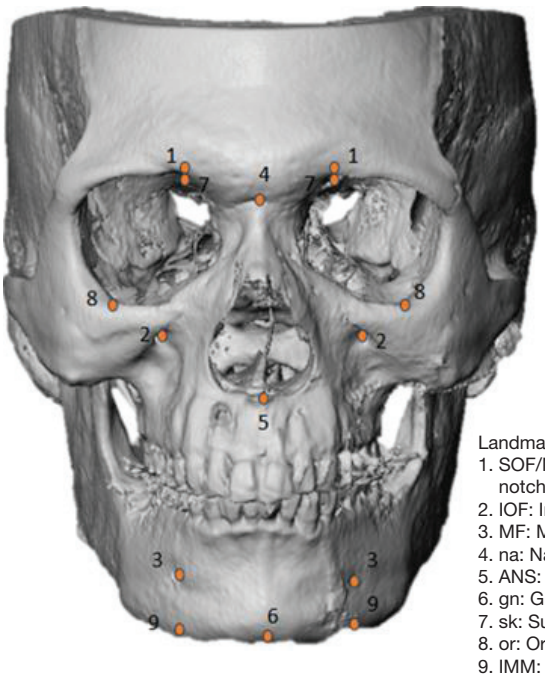
MATERIALS AND METHODS

One hundred and nine CBCT scans of adult South Africans (44 white females, 42 white males, 31 black females, and 42 black males; average age: 33 years) were included in the study. These scans were part of the retrospective collection of the Oral Health Care Centre at the Sefako Makgatho Health Sciences University and a private medical centre in Pretoria, South Africa. A Planmeca ProMax CBCT 3D scanner with the following specifications: 90kV, 8mA, 11.2 mA, voxel size of 0.4 mm^3, and a maximum field of view of 230 (diameter) mm by 260 (height) mm was used in the private hospital, while a Newtom VGi CBCT 3D scanner with the same specifications and maximum field of view was used in the Oral Health Care Centre of the Sefako Makgatho Health Sciences University. Scans with facial pathologies, fractures, or inadequate visualisation of the facial foramina were excluded. Ethical clearance was obtained from the School Research committee, with the following number: SMUREC/M/164/2022: PG.

The CBCT scans were obtained in DICOM (Digital Imaging and Communications in Medicine) format and imported into the MeVisLab © v.3.0.2 software (available from), a free medical image processing and visualisation programme. This software enables the segmentation of radiographic data, facilitating geometric morphometric and anthropological analyses.

Segmentation involves distinguishing between hard and soft tissues, based on their grey values. This is achieved by setting an ISO-value, typically ranging from 450 to 550 for soft tissue and 1450 to 1550 for hard tissue.[15] The segmentation process enables the visualisation of soft and hard tissue surfaces generated from the imported DICOM images. To optimise the visualisation of the three facial foramina under investigation, ISO-values were carefully adjusted. Additionally, the voxel sampling was set to one to ensure high-quality skull rendering. Prior to data acquisition, it was confirmed that the scans had an isometric voxel size of 0.4 mm^3, ensuring precise calculations of linear distances between 3D-placed landmarks.

The shape of the facial foramina was classified based on visual observation. The SON was classified as a notch or a foramen, while the IOF and MF were categorized as round or oval. Nine anatomical landmarks were identified from the literature[1,4,10] and 3D landmarks were placed on the segmented skull surface using the MeVisLab © v.3.0.2 software[2,9] (Fig. 1).



Landmarks:
1. SOF/N: Supraorbital foramen/ notch
2. IOF: Infraorbital foramen
3. MF: Mental foramen
4. na: Nasion
5. ANS: Anterior nasal spine
6. gn: Gnathion
7. sk: Supraconchion
8. or: Orbitale
9. IMM: Inferior mandibular margin

Figure 1: Landmark position on the 3D segmented skull surface

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The position of the facial foramina, from one landmark, - a to the other – b, was determined by calculating the linear distance between the 3D coordinates of the placed landmarks (Table I) using the Pythagorean formula.[16]

Table I: Definitions of the morphometric measurements

Measurements	nr	Definition
SOF/N-Na	1	Distance from the supraorbital notch/ foramen to the nasion
SOF/N-Sk	2	Closest distance from the supraorbital notch/foramen to the supraconchion.
IOF-Or	3	Closest distance from the infraorbital foramen to the orbitale.
IOF-ANS	4	Distance from the infraorbital foramen to the anterior nasal spine.
MF-Gn	5	Distance from the mental foramen to the gnathion.
MF-IMM	6	Vertical distance from the mental foramen to inferior mandibular margin.
SOF/N-IOF	7	Distance from the supraorbital notch/ foramen to the infraorbital foramen.
IOF-MF	8	Distance from the infraorbital foramen to the mental foramen.

Statistical analyses were performed on the calculated linear distances using the PAST statistical programme.[17] The observer error was assessed by performing an Intraclass Correlation Coefficient test (Two-way random effects, absolute agreement, single rater/measurement: ICC (2,1)).

The normality of the data was evaluated using a Shapiro-Wilk test. For each sex-population group, descriptive statistics, including summary statistics, were calculated to quantify the location of the facial foramina. Analysis of variance (ANOVA) was employed for parametric data and the Kruskal-Wallis test was used for non-parametric data, to assess variations between groups. To mitigate the risk of Type I errors arising from multiple comparisons, post hoc tests were performed. Specifically, Tukey's pairwise comparisons were used for parametric data[18-19] and Mann-Whitney tests with sequential Bonferroni correction[20] were applied for non-parametric data. Statistical significance was set at $p \leq 0.05$.

Results

ICC results, interpreted using Koo and Li's guidelines (2016),[21] showed greater measurement repeatability on the left side and higher intra-observer than interobserver reliability. Left-side supraorbital foramen (SOF) positions were more accurately determined relative to the infraorbital foramen (IOF) and nasion (na); left-side IOF relative to the anterior nasal spine (ANS); and left-side mental foramen (MF) relative to gnathion (gn). Excellent repeatability was found for SOF-IOF measurements, high repeatability for SOF-na, MF-gn, and MF-IMM, moderate repeatability for SOF-sk, IOF-ANS, and IOF-MF, and poor repeatability for IOF-or.

In the sample studied, a supraorbital notch (SON) was identified in 62.27% of cases, while the supraorbital foramen (SOF) occurred in 37.73%. Bilateral SONs were the most prevalent (44.03%), followed by unilateral SONs and SOFs (18.24% each), and bilateral SOFs (19.49%). The SON was more commonly observed on the left side, whereas the SOF was more frequently found on the right. The infraorbital foramen (IOF) was consistently present bilaterally in all individuals and was predominantly oval-shaped (72.33%). The mental foramen (MF) was reliably positioned between the mandibular premolars. Oval shapes were more common (61.64%).

The results of the Shapiro-Wilk test indicated that most linear distances calculated from the 3D coordinates followed a normal distribution across all sex-population groups, except for the SOF/N – sk distance. In addition, the following distances were non-parametric in the black male sample: Left SOF/N – na and left MF – gn. In the white female sample, non-parametric distribution was noted for the SOF/N – na on both sides as well as the right IOF – or. Lastly, the right SOF/N – na distance exhibited a non-parametric distribution in the white male sample.

Symmetry in the location of the facial foramina was observed in each sex-population group, although asymmetry was observed in the SOF/N – IOF distance in the combined sample. All three prominent facial foramina were positioned further from the midline in males compared to their female counterparts (Table II), although these positional variations were more significant in the white South African sample (Table III). The IOF was located further from the midline in black males when compared to their female counterparts, which could be due to the wider faces noted in males.

Population affinity had less influence on the position of the facial foramina (Table III). More significant variation was observed in the male sample, compared to the female sample. The SOF/N was located more lateral from the nasion (Na), and the IOF was located more lateral from the anterior nasal spine (ANS) in the black male sample compared to the white male sample, while the SOF/N was found more laterally in white males in relation to the supraconchion (Sk). The mental foramen is located further from the inferior mandibular margin (IMM) in white males compared to black males. The significant positional variations noted between females included the more lateral location of the SOF/N from the Na in black females, while the IOF was located further from the ANS in white females. The distance between the IOF and MF was more in black females compared to white females.

DISCUSSION

The accurate localisation of the supraorbital foramen/ notch, infraorbital foramen, and mental foramen is critical for the effective delivery of local anaesthesia in both surgical and dental procedures. This is particularly important in a diverse population such as South Africa, where anatomical variations are commonly observed across sex and ancestry [(16)]. Knowledge of these variations aids in the successful administration of infraorbital and mental nerve blocks, which are routinely used in dental procedures including restorations, extractions, crown preparations, and soft tissue surgeries in the anterior maxilla and mandible [(4)]. CBCT imaging offers a reliable method for assessing these landmarks, contributing to safer and more predictable clinical outcomes.[16]

In this South African sample, a bilateral SON was the most prevalent, followed by a unilateral foramen on one side and a notch on the opposite side. A bilateral SOF was least commonly observed. The findings of this study are consistent

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Table II. Basic descriptive statistics of the position of the three prominent facial foramina and asymmetry of the combined groups

Measurements	Side	Black females n=31	Black males n=42	White females n=44	White males n=42	Asymmetry (p)
SOF/N-na	R	**29.00** ± *4.82* (21.54-37.49)	**30.09** ± *4.25* (21.99- 40.79)	**26.01** ± *3.59* (18.85- 38.14)	**27.73** ± *4.07* (20.87- 38.65)	0.63
	L	**30.11** ± *4.35* (22.62-40.84)	**30.53** ± *4.75* (21.28- 42.74)	**25.53** ± *4.25* (18.21- 38.99)	**27.92** ± *3.76* (20.69- 38.80)	
SOF/N-sk	R	**3.01** ± *0.77* (2.12- 6.39)	**3.19** ± *1.44* (2.01- 11.34)	**3.13** ± *0.90* (2.09- 5.90)	**3.73** ± *0.94* (2.22- 6.96)	0.11
	L	**3.21** ± *2.23* (2.21-14.19)	**3.44** ± *0.64* (2.39- 4.94)	**3.29** ± *1.00* (2.09- 5.72)	**4.04** ± *1.76* (2.41-13.10)	
IOF-or	R	**13.92** ± *4.28* (6.82-22.63)	**14.62** ± *2.75* (6.65-19.42)	**12.96** ± *3.82* (7.03-19.25)	**14.74** ± *1.99* (11.66-19.21)	0.69
	L	**13.79** ± *3.68* (5.78-20.17)	**13.96** ± *2.56* (7.79- 20.31)	**12.79** ± *3.62* (5.34-19.90)	**15.17** ± *1.61* (12.18-18.21)	
IOF-ANS	R	**34.64** ± *3.23* (29.06-42.15)	**36.59** ± *2.63* (31.45- 42.73)	**32.67** ± *1.89* (28.40-36.87)	**35.29** ± *2.37* (30.45-39.27)	0.96
	L	**34.28** ± *2.53* (28.82-39.06)	**36.81** ± *2.58* (31.80- 43.59)	**32.65** ± *2.05* (28.08-37.56)	**35.30** ± *2.45* (29.40-39.85)	
MF-gn	R	**29.91** ± *3.01* (24.45-36.48)	**30.68** ±*3.10* (22.94-40.99)	**29.24** ± *1.98* (25.90-33.58)	**30.59** ± *2.18* (27.38-35.24)	0.08
	L	**30.02** ± *2.38* (25.71-36.45)	**31.76** ± *3.29* (26.68-42.22)	**29.66** ± *2.05* (26.12-35.71)	**30.95** ± *2.46* (24.56-35.87)	
MF-IMM	R	**11.37** ± *1.72* (8.20-16.27)	**11.51** ± *1.44* (8.86- 16.05)	**10.73** ± *1.48* (7.95-14.10)	**12.65** ± *1.14* (9.86-15.09)	0.78
	L	**11.41** ± *1.53* (8.58-15.06)	**11.54** ±*1.47* (8.11-14.99)	**10.52** ± *1.43* (7.41-14.20)	**12.60** ± *1.70* (9.10-17.11)	
SOF/N -IOF	R	**44.75** ± *2.99* (40.12- 53.27)	**46.60** ± *3.05* (40.31-53.86)	**44.55** ± *2.94* (38.90-51.05)	**46.41** ± *2.81* (41.07-52.60)	0.04*
	L	**45.73** ± *3.17* (40.70- 53.12)	**47.28** ± *3.04* (40.65-53.72)	**45.24** ± *2.88* (39.20-50.51)	**47.01** ± *2.46* (42.99-51.55)	
IOF-MF	R	**63.53** ± *5.26* (54.71- 77.52)	**66.17** ± *6.20* (51.09-83.37)	**59.86** ± *3.46* (50.24-65.64)	**65.47** ± *4 .83* (56.07-75.37)	0.66
	L	**63.44** ± *4.86* (55.65- 76.06)	**66.02** ± *5.75* (53.14- 83.92)	**59.61** ± *3.57* (51.12-66.90)	**64.91** ± *4.88* (55.97-75.30)	

Statistically significant values were indicated as follows: p<0.01** & p < 0.05*

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Table III. Variation in the position of the prominent facial foramina between sexes within populations and between populations within sexes.

Measurement	Side	Sexual dimorphism within populations		Population variation within sex groups	
		Black South Africans n=73	White South Africans n=86	SA females n=75	SA males n=84
SOF-na	R	0.68	0.03*	0.01**	0.00**
	L	0.94	0.00**	0.00**	0.03*
SOF-sk	R	0.85	0.00**	0.94	0.00**
	L	0.96	0.00**	0.57	0.00**
IOF-or	R	0.80	0.03*	0.37	0.99
	L	0.99	0.00**	0.33	0.14
IOF-ANS	R	0.01**	0.00**	0.01**	0.05*
	L	0.00**	0.00**	0.02*	0.02*
MF-gn	R	0.71	0.05*	0.69	0.99
	L	0.02*	0.10	0.94	0.50
MF-IMM	R	0.97	0.00**	0.23	0.00**
	L	0.99	0.00**	0.06	0.01**
SOF-IOF	R	0.04*	0.02*	0.99	0.99
	L	0.24	0.01**	0.89	0.97
IOF-MF	R	0.12	0.00**	0.01**	0.91
	L	0.11	0.00**	0.00**	0.72

Statistically significant values were indicated as follow: $p \leq 0.01$** & $p \leq 0.05$*

with the results published by Webster and colleagues (1986) [22] based on 108 dry Indian skulls. The SOF/N was located more laterally to the nasion in the black South African sample compared to the white South African sample, regardless of sex. This was expected, as it had been noted that black South Africans have wider facial breadths, especially the upper facial width, compared to white South Africans.[23] The effect of sex on the position of the facial foramina was more profound in white South Africans. The SOF/N were often located more laterally in males compared to their female counterparts, which is in line with the results by Chrcanovic et al. (2011)[10] where the mean distances from the SOF/N to the midline of the female crania were smaller relative to the male crania. This could be due to the prominent brow ridges noted in males, which are more pronounced in white males compared to black males.[24] These findings support the recommendation that sex and population affinity should be considered when locating the supraorbital foramen.

The infraorbital foramen (IOF) was bilaterally present in all South African specimens examined. Consistent with previous research,[9,25] the IOF was predominantly oval-shaped rather than circular. In South African males, the IOF was significantly further from the anterior nasal spine compared to their female counterparts, as reported by Chrcanovic et al. (2011)[10] on Brazilian skulls. This variation likely correlates with the greater facial width typically seen in males, resulting in a more laterally situated IOF.[26-27] White South Africans displayed notable sexual dimorphism, where all assessed IOF-related linear distances were consistently greater in males than in females. This can be attributed to the wider orbits, bizygomatic breadths, and mandibles observed in white males compared to white females.[27-28] The IOF was also located further from the ANS on the right side of the cranium than on the left side and was statistically significant in black and white South Africans. These findings agree with those reported in a previous study by Agthong and co-workers (2005).[2] However, contrary to these findings, Nanayakkara and colleagues (2016)[12] reported symmetry in the distance from the IOF to the ANS in a Thai sample.

In various population groups, the position of the infraorbital foramen (IOF) relative to the inferior orbital margin (IOM) has been reported to range between 6 and 10 mm.[12] In this South African sample, the IOF was situated slightly further from the IOM compared to findings by Chung et al. (1995)[9] and Cutright et al. (2003).[29] Notably, sexual dimorphism in IOF positioning relative to the orbitale was evident only in the white South African sample. This disparity may be attributed to historical differences in access to nutrition and healthcare, which likely contributed to more pronounced physical development and, consequently, greater visibility of sexual dimorphism.[30]

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The mental foramen was present in the entire South African sample, and as Berge and Bergman (2001)[31] reported, the mental foramen was mostly oval-shaped. The mental foramen was located significantly further from the inferior mandibular margin in white males when compared to white females and black males respectively. This indicates that the mandibular height of white males is greater, which also appears longer in proportion to its width due to a narrower jaw and less robust mandibular features.[23] No variation was noted between black males and females, nor between black females and white females.

Sexual dimorphism in the location of the MF in relation to the IOF and inferior mandibular margin was significant in the white South African sample only and greater in males. The etiology of such variation may likely be attributed to differential growth trajectories and functional adaptations [(32)]. For example, white populations often exhibit more vertical maxillary and mandibular growth, leading to an elongated lower face. Black populations typically show more forward prognathic growth, contributing to shorter but wider facial proportions.[28]

Population affinity influenced the position of the mental foramen (MF) in relation to the inferior mandibular margin, with this effect being statistically significant only in males. White South African males exhibited greater values compared to their black South African counterparts. However, the overall distance to the inferior rim of the mandible was consistent with findings from other studies, ranging approximately between 11 and 15 mm.[33] Notably, all scans in the present study were from dentate individuals, leaving open the question of whether edentulous would affect the distance between the MF and the inferior mandibular margin. Additionally, the average distance between the MF and gnathion (gn) was greater in this sample compared to findings reported for Korean[9] and white American populations[29] due to South Africans having a higher ramus height and a broader mandibular corpus, resulting in the appearance of more prominent jawlines compared to Koreans and White Americans.[34]

The Limitation of this study include an unequal sample size despite incorporating private facility scans. A larger and more representative cohort could yield more informative results, in particular using the same modality and comparing with studies in other African countries, such as Angola, Kenya, Nigeria, and Tunisia, would be beneficial. Future research should also assess the facial width and breadth to express the facial foramen location as a ratio for greater utility.

Conclusion

The study revealed that a supraorbital notch (SON) was observed more frequently than a supraorbital foramen (SOF), while the infraorbital foramen (IOF) and mental foramen (MF) were predominantly oval. Notably, the facial foramina in black South Africans were generally located farther from selected bony landmarks compared to white South Africans. Additionally, pronounced sexual dimorphism was observed in the white South African sample, with males exhibiting larger dimensions than their female counterparts. However, no asymmetry was detected in the positions of the three prominent facial foramina across any sex or population groups.

These findings contribute to the growing body of knowledge on the morphometrics of the SOF/N, IOF and MF, particularly within South African populations. The ability to accurately identify the locations of these foramina is critical for minimising the risk of injury to neurovascular structures during surgical procedures. The observed differences related to sex and population emphasise the importance of tailored approaches when performing surgical interventions or administering regional nerve blocks in the maxillofacial region, to mitigate potential complications.

Take home message: The anatomical locations of the supraorbital foramen/notch (SOF/N), infraorbital foramen (IOF), and mental foramen (MF) show significant variation among sexes and populations, emphasising the need for tailored approaches in aesthetic surgical procedures. In black South Africans, the foramina are generally positioned further from midline landmarks due to broader facial dimensions, with black males exhibiting more lateral placement of the SOF and IOF relative to the nasion and anterior nasal spine (ANS). In contrast, white South Africans presented with more pronounced sexual dimorphism, as the facial foramina were located significantly further from the midline in males compared to females. The MF was located higher relative to the inferior mandibular margin (IMM) compared to females. These variations necessitate targeting the SOF, IOF, and MF more laterally in males, particularly black males, and higher for mental nerve blocks in white males. The accurate localisation of these foramina is critical to improving nerve block efficacy and reducing complications in maxillofacial procedures.

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