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Morphometric Analysis of the Mental Foramen Using Cone-beam Computed Tomography in the Salem Population

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Research Article

Keywords: Accessory mental foramen, cone-beam computed tomography, mandibular morphometry, mental foramen, sexual dimorphism, mandible

Posted Date: March 8th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-8866468/v1

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Additional Declarations: No competing interests reported.

Abstract

The mental foramen (MF) is a morphological feature in the mandible through which the mental nerve and arteries pass. It is situated between the roots of the lower premolar region or apical to the second premolar. The identification and localization of the MF are essential in various dental and operative procedures, including implant placement, fracture fixation, and orthognathic surgery. Variations in its position, size, and the existence of accessory foramina can impact the course and outcome of operative interventions. The primary aim of this prospective analytical study is to analyze the morphometry of the mental foramen (MF) and the presence, location, and morphology of the accessory mental foramen (AMF) using cone-beam computed tomography (CBCT) in the Salem population. The objectives of the study include evaluation of the size, shape, and position of MF, investigating the presence of any accessory mental foramen (AMF), and determining its location. This prospective descriptive study assessed the mental foramen and the presence and location of an accessory foramen in 60 patients (30 males, 30 females; aged 20–60 years) using a Carestream CS9600 cone beam computed tomography scanner. The mean superior, inferior and mediolateral measurements of the MF were both 2.9 mm. Males exhibited significantly greater MF dimensions than females ($p < 0.05$). The predominant MF position was on the same plane as the 2nd premolar (P4, 56.7%), followed by between the 1st and 2nd premolars (P3, 35%). The most frequently observed MF shape was test-tube (33.3%), followed by dumbbell (20%) and flask (16.7%). AMFs were present in 31.7% of subjects, predominantly located anterior to the main MF. The vertical height from the MF to the mandibular base was significantly greater in males ($p = 0.001$). A negative association was observed between age and the perpendicular height from the MF to the crest of the alveolar bone. MF exhibits significant anatomical variability in size, shape, and location, often influenced by sex, underscoring the need for personalized evaluations in treatment planning. Uncommon MF shapes, such as test-tube and dumbbell forms, challenge traditional round/oval depictions, emphasising 3D CBCT imaging over conventional anatomy. In the lower premolar region, the prevalence of AMF (31.7%) was significantly higher than previously reported, confirming the diagnostic value of CBCT and the need for its routine use before invasive dental treatments in mandibular premolar areas.

Introduction

The Mental Foramen (MF) is a pivotal anatomical feature on the anterolateral surface of the mandible, transmitting the mental nerve, artery, and vein, which are branches of the inferior alveolar nerve bundle. This foramen plays a crucial role in the sensory innervation of the lower lip, chin, anterior teeth, and labial mucosa, making it highly significant for various dental and operative procedures, including local anesthesia, periapical surgery, implantology, and orthognathic surgeries. Beshtawi KR, and Qirresh E (2024) stated the incidental reporting of mental foramen in CBCT during implant treatment planning. Variations in the location, dimensions, and presence of AMF can lead to complications such as ineffective anesthesia, nerve injury, or unintended bleeding during surgery. These variations underscore the need for region-specific studies that provide precise, high-resolution imaging of MF characteristics, such as CBCT, which offers 3-dimensional, distortion-free visualization compared to traditional imaging

techniques like panoramic radiographs (Von Arx T et al., 2019) (Coban D et al., 2025) (Koc N, Dural S.2025) (Orlowska M et al.2025).While a large body of literature has been dedicated to MF anatomy, there remains a significant lack of population-specific data, particularly in regions with unique ethnic or geographical characteristics. This research aims to fill this gap by analyzing morphometric and topographic characteristics of the MF in a South Indian (Salem) population, offering novel insights into its anatomical features and variation within this demographic. The use of CBCT in our study ensures greater precision in identifying MF characteristics, such as position, shape, size, and the presence of accessory foramina, compared to traditional imaging techniques.

Ethical considerations

This prospective descriptive-analytical study was carried out at the institution, with approval from the Institutional Ethics Committee, Vinayaka Mission's Sankarachariyar Dental College, Vinayaka Mission's Research Foundation (Deemed to be University), Salem, Tamilnadu, India, VMSDC/ IEC/Approval No. 372. The study was conducted after obtaining informed consent from patients visiting the institution for dental evaluation of the mandibular premolar area, in accordance with the Declaration of Helsinki. The patient's images were deidentified to remove anonymity. The inclusion criteria included the following. Men and women aged 20–60 years with intact dentition in the mandibular premolar region, referred for routine dental evaluations, as indicated by CBCT images of the mandibular premolar region.

The exclusion criteria included the presence of periapical pathologies, such as periapical abscesses, cysts, and granulomas, in the mandibular premolar region. Presence of an impacted supernumerary tooth in the mandibular premolar region. Congenitally missing premolars in the mandibular region. Completely edentulous dental arches. Subjects with edentulous arches in the premolar region, or with skeletal or dental anomalies or pathologies, such as odontogenic cysts or tumours that cause bone expansion and alter the configuration of the MF. Fibro-osseous conditions, such as fibrous dysplasia, can alter bone structure and obscure the MF because of their ill-defined borders. Additionally, systemic disorders like secondary hyperparathyroidism, which causes significant alveolar bone loss, and osteodystrophies such as Paget's disease, which can lead to the narrowing or complete loss of the MF, also contribute to these changes.

Study Type:

The present study is a prospective, descriptive-analytical study conducted between January 2025 and May 2025 to analyze morphometric changes and variations in the anatomical configurations of the mental foramen using CBCT imaging with the Carestream CS 9600 CBCT scanner.

Sample Size Calculation for comparing two independent groups (Females vs Males)

The sample size was calculated using the G-Power software analysis, A priori: Compute required sample size. Input: Effect size f = 0.5, α error probability = 0.05, Power (1-β error probability) = 0.80, Number of groups = 2, Number of measurements = 4, which revealed total sample size = 26 in each group. Actual power = 0.8063175. The minimum required Sample Size is 26. Hence, the sample size was rounded to 30 per group. The exact number of males (n = 30) and females (n = 30) was considered to enhance the generalizability of the findings and to prevent potential gender bias in the study results. Cohen's d effect size was 0.2, which is minimal.

Study design

This study involved 60 patients (30 males, 30 females; aged 20–60 years) referred to the Radiology Department for CBCT imaging for pre-surgical planning, implant evaluation, endodontic assessment, and various other procedures. Sixty volunteers—30 male and 30 female subjects—who met the above-mentioned predefined inclusion criteria were enrolled. After a thorough explanation of the procedure, each participant provided written informed consent. Baseline demographic details (name, age, sex) were recorded electronically. To reduce radiation exposure, each participant wore a lead apron and thyroid collar before imaging. The CS 9600 CBCT device (Carestream Health, Inc., Rochester, New York, USA) was used for imaging. Segmental CBCT imaging was performed with a voxel resolution of 75 µm and a field of view (FOV) of 6×6 cm. The scanning protocol was set to 120 kV, 6.3 mA, and 19.0 seconds. A single CBCT exposure resulted in a radiation dose of 894 mGy·cm², as per National Council on Radiation Protection and Measurements (NCRP) recommendations, remaining below the 2.4 mSv upper exposure limit. Subjects stood upright between the CBCT X-ray source and detector for each scan, with the floor parallel to the Frankfort horizontal (FH) plane. The jaws were stabilized with a bite block, and the head was held firmly in place with lateral headrests to reduce patient movement during radiographic imaging. An initial low-dose scout projection confirmed complete coverage of the target anatomy. The definitive volumetric acquisition followed immediately, lasting 6–10 seconds. After primary reconstruction, the axial and three-dimensional images were reviewed on-screen to verify exposure quality. The secondary reconstruction was finished within 15 minutes, and the final images were stored for analysis. Using the tools in the CBCT program, Carestream CS 3D Imaging, version [3.10.43], these images were used to assess the MF's size, shape, and location, as well as to determine whether supplementary MF were present.

Radiographic measurements of Mental Foramen (MF)

The following parameters were evaluated using CBCT to analyze the size, shape, and position of the mental foramen (MF) and the presence and location of the AMF. The size of the Mental foramen (MF) was assessed in coronal slice sections in CBCT as Superoinferior Dimension of MF (SI) (mm) and Mediolateral Dimension of MF (ML) (mm) (Fig. 1).

The distance of mental foramen was assessed as Distance A, the distance from the root apex of the 1st premolar to the Superior Border of MF (mm) in 2D Reconstructed Panoramic View using and Distance B, the distance from the root apex of the 2nd premolar to the Superior Border of MF (mm) – 2D Reconstructed Panoramic View, Distance C: Superior Border of MF to Alveolar Crest (mm) - Oblique Coronal View, Distance D: Inferior Border of MF to Base of Mandible (mm) - Oblique Coronal View using Carestream CS 3D Imaging Software (version 3.10.43) (Fig. 2A, 2B).

The position of the mental foramen was assessed with volumetric scan image obtained using Carestream CS 3D imaging Software (Version 3.10.43) as P1: A vertical line drawn anterior to the long axis of the mandibular 1st premolar, P2: A vertical line aligned with the long axis of the root of the mandibular 1st premolar, P3: A vertical line positioned between the long axes of the roots of the mandibular 1st and 2nd premolars, P4: A vertical line following the long axis of the root of the mandibular 2nd premolar, P5: A vertical line placed between the long axes of the mandibular 2nd premolar and 1st molar, P6: A vertical line aligned with the long axis of the mesial root of the mandibular 1st molar (Fig. 3).

The location of accessory foramen was determined in a 3D reconstructed volumetric view in CBCT as superior, inferior, anterior and posterior AMF (Fig. 4, A, B, C, D).

Results

The analysis included continuous variables, including linear distances A, B, C, and D, as well as the superior-inferior (SI) and mediolateral (ML) dimensions of the mental foramen (MF). Categorical variables included sex, age groups, positions of the MF (P1–P6), shapes of the MF, presence or absence of accessory mental foramen (AMF), and their anatomical locations. Differences in these variables were assessed using appropriate statistical tests. The participants' ages ranged from 20 to 60. Their mean age was 35.2 years. Most participants (71.7%) were in the 20–40 age group, with 36.7% in the 31–40 age group and 35% in the 20–30 age group. Fewer participants were older, with 20% aged 41–50 and only 8.3% aged 51–60 (Table 1).

Table 1
Distribution of Age and Gender among Study Participants

Variables	Categories	Frequency	Percentage
Age	20–30	21	35
	31–40	22	36.7
	41–50	12	20
	51–60	5	8.3
Mean ± SD	35.2 ± 9.7		
Gender	Male	30	50
	Female	30	50

The 60 participants were evenly divided between males and females. Both males and females accounted for 50% (n = 30) of the total sample. The coronal section's SI dimension had a mean value of 2.9 mm, along with a standard deviation (SD) value of 0.6 mm. Measurements varied from 1.9 mm to 4.1 mm, with a median value of 3.0 mm. Additionally, the mediolateral (ML) dimension had a median of 2.8 mm, a range of 2.0 mm to 4.2 mm, and a mean of 2.9 mm with a standard deviation of 0.6 mm. The distance from the apex of the 1st premolar to the superior border of the MF (Distance A) showed a mean of 5.3 mm (SD = 2.4 mm), with a median of 5.2 mm and a range of 0.5 to 10.5 mm. The distance from the apex of the 2nd premolar to the superior border of the MF (Distance B) had a mean of 3.0 mm, SD of 2.0 mm, and a median of 2.5 mm, with values ranging from 0.1 to 11.5 mm. In the oblique coronal section, the distance from the superior outline of the MF to the crest of the mandibular alveolar bone (Distance C) was relatively consistent, with a mean of 12.1 mm, SD of 2.2 mm, median of 12.05 mm, and a range of 6.1 to 18.2 mm. Lastly, the distance from the inferior border of the MF to the lower border of the mandible (Distance D) showed a mean of 12.2 mm, SD of 1.5 mm, median of 12.25 mm, and a narrower range of 9.2 to 16.2 mm, indicating the least variability among all measured distances (Table 2).

Table 2
Comparison of the Shape and Position of Mental Foramen (MF) among Male and Female

Variable	Male	Female	p- value
Shape of MF			0.975
Oval	2(6.7)	2(6.7)	
Dumbbell	5(16.7)	7(23.3)	
Flask	5(16.7)	5(16.7)	
Hockey-stick	4(13.3)	3(10)	
Test-tube	11(36.7)	9(30)	
Irregular	3(10)	4(13.3)	
Position – P2	1(3.3)	0(0)	0.666
P3	10(33.3)	11(36.7)	
P4	17(56.7)	17(56.7)	
P5	1(3.3)	2(6.7)	
P6	1(3.3)	0(0)	

Shapes of Mental Foramen

The shape of the mental foramen varied among participants, with the most common form being the test tube shape, observed in 33.3% (n = 20) of cases. The dumbbell shape followed this at 20% (n = 12) and the flask shape at 16.7% (n = 10). The hockey stick and irregular shapes were each seen in 11.7% (n = 7) of participants. The oval shape was the least observed in only 6.7% (n = 4).

Position of Mental Foramen

The most frequent position of the mental foramen was P4, observed in 56.7% (n = 34) of participants, followed by P3 in 35% (n = 21). Less common positions included P5 (5%; n = 3) and P2 and P6, each found in only 1.7% (n = 1) of cases. No cases were reported in the P1 position (Fig. 5A, B, C).

Accessory Mental Foramen

An AMF was identified in 31.7% (n = 19) of participants, while it was absent in 68.3% (n = 41).

Location of Accessory Mental Foramen

In 15% (n = 9) of the people with an AMF, the placement was most frequently anterior to the main MF. The posterior position was observed in 8.3% (n = 5), the superior position in 5% (n = 3), and the inferior position in 3.3% (n = 2). The distribution of age groups between males and females showed there is no significant association (p = 0.118). In the 20–30 age group, 23.3% of males and 40% of females were represented. In the 31–40 age group, 23.3% of males and 36.7% of females were observed. A higher proportion of males (33.3%) were in the 41–50 age group than females (16.7%). The 51–60 age group had 20% of males and only 6.7% of females. The superoinferior (SI) dimension was significantly greater in males (3.1 ± 0.6 mm) compared to females (2.7 ± 0.5 mm), with a p-value of 0.006. Similarly, the mediolateral (ML) dimension was larger in males (3.0 ± 0.6 mm) than in females (2.7 ± 0.5 mm; p = 0.039). Statistically significant differences were observed between males and females in both measured dimensions of the mental foramen. No statistically significant differences were observed between males and females in Distance A (Apex of 1st Premolar to Superior Border of MF, p = 0.749), Distance B (Apex of 2nd Premolar to Superior Border of MF, p = 0.342), and Distance C (Superior Border of MF to Alveolar Crest, p = 0.864). However, Distance D (Inferior Border of MF to Lower Border of Mandible) was statistically significantly greater in males (13.0 ± 1.4 mm) compared to females (11.4 ± 1.3 mm), with a p-value of 0.001. The distribution of MF shapes between males and females showed there is no significant association (p = 0.975). Both sexes had an equal proportion of oval shapes (6.7%). The dumbbell shape was more common in females (23.3%) than males (16.7%), while the flask shape was equally distributed (16.7% for both sexes). The hockey stick shape of the MF was slightly more common in males (13.3%) than in females (10%), while the test tube shape was more common in males (36.7%) than in females (30%). The irregular shape appeared slightly more in females (13.3%) than in males (10%). Overall, no significant sexual dimorphism was observed in the distribution of MF shapes (p = 0.975). There was no statistically significant association between the position of the MF and sex (p = 0.666). The standard position in both males and females was P4, observed in 56.7% of cases. P3 was the following most frequent location, found in 33.3% of males and 36.7% of females. Other positions, such as P2, P5, and P6, were rarely observed and showed similarly low frequencies across sexes (Table 3).

Table 3
Sex-based comparison of dimensions and anatomical distances related to the mental foramen

Variable	Male (n = 30)	Female (n = 30)	p-value
Supero-inferior Dimension (SI)	3.1 ± 0.6	2.7 ± 0.5	0.006
Medio-Lateral Dimension (ML)	3.0 ± 0.6	2.7 ± 0.5	0.039
Distance from Apex of 1st Premolar to Superior Border of MF - Distance A	5.4 ± 2.7	5.2 ± 2.1	0.749
Distance from Apex of 2nd Premolar to Superior Border of MF - Distance B	3.3 ± 2.3	2.8 ± 1.7	0.342
Distance from the Superior Border of MF to Alveolar Crest - Distance C	12.0 ± 2.5	12.1 ± 2.0	0.864
Distance from Inferior Border of MF to Base of Mandible - Distance D	13.0 ± 1.4	11.4 ± 1.3	0.001

The distribution of MF positions (P2–P6) showed no statistically significant association across age groups (p = 0.675). Position P4 was the predominant across all age groups, ranging from 52.4% in the 20–30 years group to 80% in the 51–60 years group. Position P3 was the 2nd most frequent, particularly among individuals aged 20 to 40 years. Positions P2, P5, and P6 were rare and observed only in isolated cases. Overall, P4 was the predominant location for the MF, and its position was essentially constant across age groups (Table 4).

Table 4
Comparison of Mental Foramen (MF) Positions across age groups

Variables	Age 20–30 yrs	31–40 yrs	41–50 yrs	51–60 yrs	p-value
Position P2	0(0)	0(0)	1(8.3)	0(0)	0.675
P3	8(38.1)	9(40.9)	3(25)	1(20)	
P4	11(52.4)	11(50)	8(66.7)	4(80)	
P5	1(4.8)	2(9.1)	0(0)	0(0)	
P6	1(4.8)	0(0)	0(0)	0(0)	

There was no statistically significant association in the presence of the AMF between males and females (p = 0.781). 30% of males and 33.3% of females had an AMF, while 70% of males and 66.7% of females did not exhibit this anatomical variation (Table 5).

Table 5
Comparison of the Presence and Location of Accessory Mental Foramen (AMF) between Males and Females

Variable	Male	Female	p-value
Presence of Accessory Mental Foramen (AMF)			
Present	9(30)	10(33.3)	0.781
Absent	21(70)	20(66.7)	
Location of AMF with respect to MF			
Superior	1(11.1)	2(20)	0.898
Inferior	1(11.1)	1(10)	
Anterior	5(55.6)	4(40)	
Posterior	2(22.2)	3(30)	

The Pearson-Chi-square correlation analysis (Table 6).

Table 6
Correlation Analysis of MF-Related Measurements

Variable	Superoinferior Dimension (SI)	Mediolateral Dimension (ML)	Distance from Apex of 1st Premolar to Superior Border of MF - Distance (A)	Distance from Apex of 2nd Premolar to Superior Border of MF - Distance (B)	Distance from the Superior Border of MF to Alveolar Crest - Distance (C)	Distance from Inferior Border of MF to Base of Mandible - Distance (D)
Superoinferior Dimension - SI (mm) Pearson-chi square correlation	**1**	**0.670**	**-0.32**	**-130**	**-0.74**	**.452****
Sig.(2-tailed)	**0**	**0.000**	**0.808**	**0.323**	**0.184**	**0.000**
Mediolateral Dimension – ML (mm) Pearson-chi square correlation	0.670**	1	0.131	-0.83	-0.53	0.381**
Sig.(2-tailed)	0.000		0.317	0.528	0.686	0.003
Distance from Apex of 1st Premolar to Superior Border of MF - Distance A (mm) Pearson-chi square correlation	-0.032	0.131	1	0.022	0.438**	0.007

The distribution of AMF locations—superior, inferior, anterior, and posterior—relative to the MF showed no statistically significant association between males and females (p = 0.898). Among males, the anterior location was predominant (55.6%), followed by posterior (22.2%), with superior and inferior locations each accounting for 11.1%. Similarly, in females, the anterior location was also the most frequent (40%), followed by posterior (30%), superior (20%), and inferior (10%). The combined scatter plot and heat map distribution among male and female groups (Fig. 6).

The combined heat map representation of SI and ML dimensions of mental foramen (MF) by position, age group and Accessory mental foramen (AMF) (Fig. 7A, B).

Discussion

Age Distribution

The study participants were aged 20–60 years (mean: 35.2 ± 9.7 years), with the most significant proportion (71.7%) aged 20–40 years. Notably, there was no significant association between age and the horizontal position of the MF ($p = 0.675$). However, a weak negative correlation was found between age and the vertical distance from the MF to the alveolar crest ($r = -0.286$, $p = 0.027$), consistent with age-related changes in bone resorption, particularly in the posterior alveolar ridge. Muinelo-Lorenzo et al. (2017) and Pelé et al. (2021) similarly reported that advancing age is associated with a reduction in alveolar bone height, thereby affecting the MF's vertical position. However, several authors have suggested that the MF remains largely stable in its anatomical location throughout adulthood, highlighting the ongoing debate over age-related variation.

Dimensions of the MF

The mean superior-inferior (SI) and mediolateral (ML) dimensions of the MF in our study were both 2.9 ± 0.6 mm. A sex-based analysis revealed significantly larger MF dimensions in males (SI: 3.1 ± 0.6 mm; ML: 3.0 ± 0.6 mm) compared to females (SI: 2.7 ± 0.5 mm; ML: 2.7 ± 0.5 mm), with p-values of 0.006 and 0.039, respectively (Table 6). This finding is consistent with Mashyakhy et al. (2021), Ghandourah et al. (2023), Bagheri S et al. (2023), and Rath R et al. (2023), who also observed sexual dimorphism in MF dimensions. Larger foramina in males may be attributed to broader mandibles, a feature commonly seen in men due to sexual dimorphism in skeletal structure. Compared with previous studies, the MF dimensions in our cohort were smaller than those reported by Al-Mahalawy et al. (2017) (mean diameter: 3.66 mm, Saudi Arabia) but larger than those reported by Muinelo-Lorenzo et al. (2015) (mean diameter: 1.88 mm, Spain). These discrepancies emphasize the ethnic variability in mandibular morphology, which is influenced by genetic, environmental, and dietary factors. Thus, the observed differences in MF size can be attributed to ethnic and regional differences in mandibular bone development.

Position of the MF

In terms of MF position, our study found the predominant location to be in line with the 2nd premolar (P4) (56.7%), followed by between the 1st and 2nd premolars (P3) in 35% of cases. This finding aligns with the results of Shalash et al. (2020), Pelé et al. (2021) (50.3–57.9% P4), Sheth et al. (2022), Abu Ta'a et al. (2023), Fontenele RC et al. (2023), Ghandourah et al. (2023), Cimen T et al. (2025), Coban D etal. (2025) and Kim YH and Hur MS (2025), all of whom reported that the P4 position is the most prevalent. The high occurrence of MF alignment with the second premolar is significant because it is directly linked to clinical procedures such as implant placement and local anesthesia, where precise identification of MF position is essential to avoid nerve damage. Interestingly, no significant differences in MF position

were found between sexes (p = 0.666) or across age groups (p = 0.675), suggesting that the MF position remains consistent across demographics.

Shape of the MF

The predominant MF shape observed in this study was the test tube configuration (33.3%), followed by the dumbbell (20%), flask (16.7%), hockey stick (11.7%), and oval (6.7%). This distribution differs from that reported in the literature by Chappidi et al. (2019), Alrahabi et al. (2018), and Sheth et al. (2022), which reported oval-shaped foramina as the predominant type. The test-tube shape was notably more prevalent in our study, which may reflect more refined CBCT imaging techniques that enable better identification of intricate foramen shapes. No significant difference was observed between sexes concerning MF shape (p = 0.975), consistent with studies by Kalender A et al. (2012) and Ghandourah et al. (2023). Our study results were contradictory to those of Kim YH and Hur MS (2025), who stated that round shapes of the mental foramen were more common in 16 dentate Korean cadavers. In contrast, in our study, test-tube-like shapes were predominant among males and dumbbell-shaped among females.

Accessory Mental Foramina (AMF)

Accessory mental foramen identification is of utmost importance, as it prevents the risk of nerve injury, as it communicates with the mandibular canal and innervates adjacent teeth near the mandibular premolar area (Barbosa DAF et al.2024). AMFs have been identified in about 31.7% of subjects in this study (30% in males and 33.3% in females), which is significantly higher than the 7% incidence reported by Naitoh et al. (2009) and Zmyslowska-Polakowska et al. (2017) in other populations. The ability of CBCT to detect smaller foramina is likely responsible for this higher detection rate. Pelé et al. (2021) highlighted that CBCT is superior to conventional radiographs in identifying even small foramina, and our findings support this claim. The predominant location for AMF involved anterior (15%), posterior (8.3%), superior (5%), and inferior (3.3%). Torres et al. (2015) and Iwanaga et al. (2015) observed that posterior AMFs were more common. The anterior predominance in our study suggests possible regional or ethnic variations in the distribution of AMFs. Further studies on AMF occurrence across diverse populations could provide insights into genetic and developmental influences on mandibular foramina. 14 (representing 44%) were positioned anterior-superiorly to their respective prominent mental foramina, according to Oliveria Santos C et al. (2010). Our study contradicted the results of Aljarbou F et al. (2021) and Coban D et al. (2025), who reported that the accessory mental foramen is most often located in the posterior and inferior regions, rather than the anterior region observed in our study.

Distances from Surrounding Structures

In this study, the average distances from the MF to various surrounding structures were as follows: Distance A (apex of 1st premolar to MF): 5.3 ± 2.4 mm, Distance B (apex of 2nd premolar to MF): 3.0 ± 2.0 mm, Distance C (superior border of MF to alveolar crest): 12.1 ± 2.2 mm, Distance D (inferior border of MF to mandibular base): 12.2 ± 1.5 mm. Statistical significance was found in Distance D, with males showing greater vertical MF-mandibular base distances (13.0 ± 1.4 mm) compared to females (11.4 ± 1.3 mm, p = 0.001). These findings support the conclusions of Sheikhi and Kheir (2016), Dos Santos et

al. (2018), and Mashyakhy et al. (2021), who also found sexual dimorphism in the vertical positioning of the MF.

Clinical Relevance

Understanding the morphology of the MF is of utmost importance in clinical dentistry, particularly in implantology, endodontics, and orthognathic surgery. Variations in MF position and the presence of AMFs are critical factors in ensuring accurate local anesthesia, preventing nerve damage, and minimizing operative risks. The higher frequency of AMFs in our study underscores the importance of preoperative imaging, with CBCT serving as a valuable tool for accurately mapping MF and AMF locations to avoid complications.

Anthropological and Forensic Significance

The morphometric information derived from this research has practical applications in forensic science, especially in sex identification, and could be used to develop anthropological databases. Recording regional MF values contributes to understanding evolutionary patterns and mandibular growth, providing essential insights into human masticatory evolution. Documenting regional MF characteristics helps understand evolutionary traits and mandibular development, providing valuable insights into human masticatory adaptations.

Novelty of the Study

This study represents one of the first efforts to document MF characteristics and the occurrence of AMFs in the Salem population using CBCT, providing novel anatomical insights. Previous studies have described the MF as oval or round, overlooking other variations. In contrast, this study identifies additional morphological shapes, including test tube, flask-like, hockey stick, and dumbbell, visualised in oblique coronal CBCT sections, thereby enhancing the need for CBCT for its diagnostic accuracy.

Strengths

The morphological assessment of the mental foramen using high-spatial resolution CBCT imaging with minimal elongation error. A balanced male-to-female distribution in the sample prevents Type II (false-negative) statistical error, provides generalizability, and prevents gender-induced bias in the results—multi-planar analysis conducted by two independent, well-trained radiology observers. A comprehensive evaluation of MF dimensions, position, shape, and location of accessory mental foramina (AMF) was performed.

Limitations

The study population was restricted to a single-centre sample of dentate individuals; findings may not apply to edentulous or paediatric patients. A morphometric comparison, such as the number, diameters of the right and left MF in both sides of the mandible and Accessory or Additional Mental Foramen (AMF), including their number asymmetry, was not considered. The possible impact of systemic

diseases on MF morphology was not assessed. Studies comparing integrated software tools such as Mimics (Materialise Naamloze Vennootschap - NV), OsiriX, Xoran software, i-CAT Vision with i-CAT-FLX, NNT (NewTom), and non-integrated tools such as MorphJ, 3D Slicer, MicroDICOM, RadiANT DICOM viewer, and On-Demand 3D assess the mental foramen in CBCT. The lack of Deep learning models like EfficientDet-D0 and YOLO variants (e.g., YOLOv8, YOLOv11), which enhance AI-driven segmentation, automated detection, and diagnosis, and provide precise clinical anatomical details of the mental foramen.

Conclusion

This study provides a comprehensive CBCT-based assessment of morphometric and topological features of the mandibular foramen (MF) and accessory MF (AMF) in the Salem population. MF exhibits significant anatomical variability in size, shape, and location, often influenced by sex, underscoring the need for personalized evaluations in treatment planning. Notably, AMF prevalence reached 31.7% in the lower premolar region—higher than prior reports—reinforcing CBCT's diagnostic superiority for pre-invasive procedures. Age and sex modulate MF's spatial relationships with nearby structures, impacting dental procedures such as implantology, endodontics, and anesthesia. The second premolar consistently marks the MF's horizontal position, serving as a reliable clinical landmark. Uncommon MF shapes, such as test-tube and dumbbell forms, challenge traditional round/oval depictions, underscoring the importance of 3D CBCT imaging over conventional imaging in clinical morphometric assessment of its anatomy. Age-related bone remodelling alters MF position and vertical bone height, which is critical for elderly treatment plans. Overall, this research provides population-specific data, advocating routine CBCT to enhance precision in MF localization, positioning, and morphological variation.

Future Directions

The study population was restricted to a single-centre sample of dentate individuals; findings may not apply to edentulous or pediatric patients due to a lack of AI-driven segmentation for automated, precise analysis of MF and AMF. A morphometric comparison, such as the number, diameters of the right and left MF in both sides of the mandible and Accessory or Additional Mental Foramen (AMF), including their number asymmetry, was not considered. The possible effects of systemic diseases on MF morphology were not considered. Studies comparing integrated software tools such as Mimics (Materialise NV), OsiriX, Xoran software, i-CAT Vision with i-CAT-FLX, NNT (NewTom), and non-integrated tools such as MorphJ, 3D Slicer, MicroDICOM, RadiANT DICOM viewer, and On-Demand 3D help assess the mental foramen in CBCT. Future studies should integrate artificial intelligence (AI)-based morphometric analysis using software tools such as 3D-Unet and Medical Open Network for Artificial Intelligence (MONAI), an open-source PyTorch-based deep learning framework for medical imaging, to further enhance the precision of MF evaluation. AI-driven tools can enhance automatic detection and segmentation and calibrate the areas of MF and AMF, which are essential but may be overlooked or missed during radiological interpretation. Adaptation of AI Domain models and cloud-based AI tools like Diagnocat, Pearl, Relu Besloten Vennootschap (BV) Creator, and Dentiquenet for real-time navigation and

mandibular segmentation, and for federated learning across multi-centric hospitals. Integration of scSE (spatial and channel Squeeze-and-Excitation) in 3D-U-Net, called Attention 3D U-Net, excels in dental CBCT segmentation by focusing on spatial-channel details, enhancing the accuracy of the edges of anatomical structures, removing ambiguity in boundaries, and assessing small-diameter accessory mental foramina, while suppressing irrelevant mandible regions and highlighting small structures such as accessory mental foramina, which may be overlooked in CBCT. Larger, multi-ethnic cohorts and longitudinal follow-up are required to examine ethnic and age-related changes in MF morphology.

Declarations

Acknowledgements: The authors disclose the use of Python, Matplotlib (with Pandas), for combined scatterplot and heatmap distribution images.

Funding: None.

Data availability statement: Data available on request from the corresponding author.

Conflicts of interest: The authors declare no competing interests.

Ethics approval (Human rights / Helsinki):

This study was approved by the **(Vinayaka Mission's Sankarachariyar Dental College, Vinayaka Mission's Research Foundation (Deemed to be University), Institutional Ethics Commitee** (VMSDC/IEC/Approval No. **372**) and was performed in accordance with the ethical standards laid down in the **Declaration of Helsinki** and its later amendments.

Consent to participate (Patient declaration):

Informed consent was obtained from all individual participants included in the study.

Author Contribution

MA Data collection, Conceptualization, Statistical analysisRRGV Supervision, Data collectionKRRM Manuscript writing, Data collection, Study design, Literature reviewSMF Literature review, Conceptualization, DesignKA Design, Literature reviewRRST Concept, Design, Data collection, Literature reviewIJMR Literature search, Literature collection, Concept, Design

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Figures

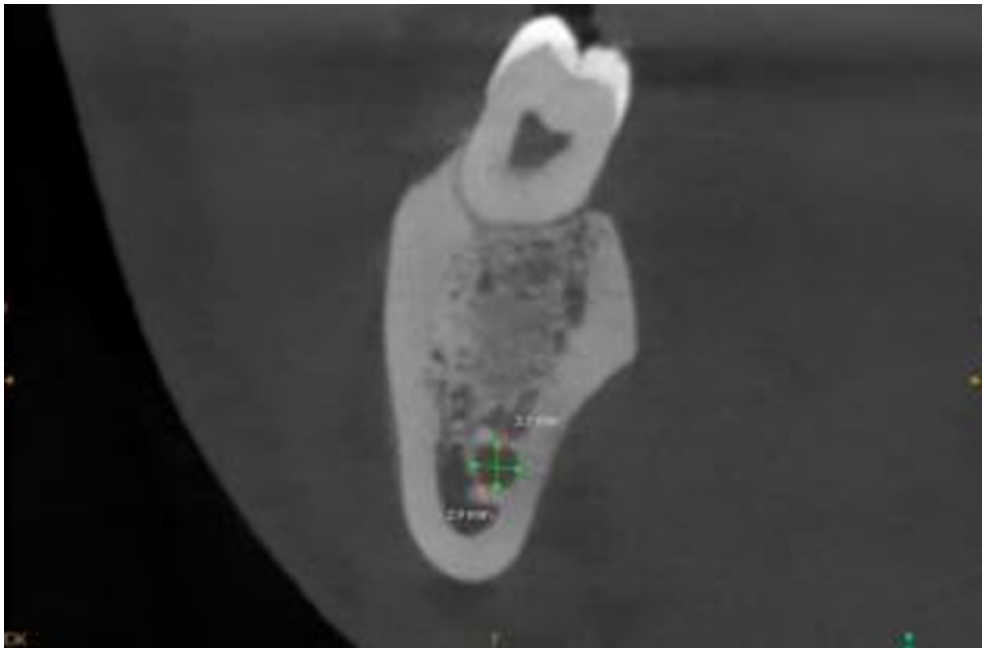


Figure 1

Superoinferior Dimension (SI) (mm) and Mediolateral Dimension of MF (ML) (mm) of Mental Foramen in Coronal slice Computed Tomography (CBCT).

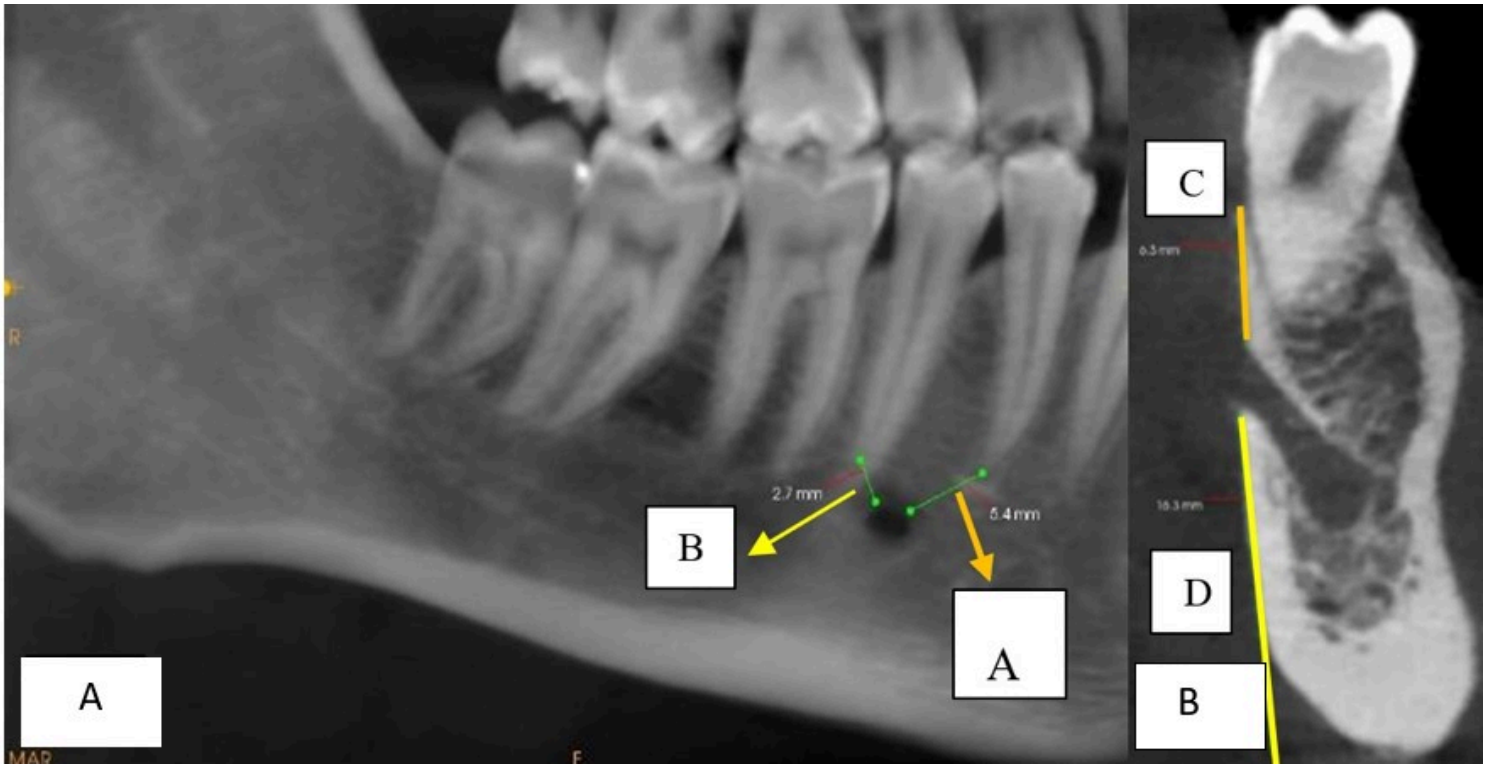


Figure 2

A. Distance A, the distance from the root apex of the 1st premolar to the Superior Border of MF (mm) in 2D Reconstructed Panoramic View-CBCT

B. Distance B, the distance from the root apex of the 2nd premolar to the Superior Border of MF (mm) – 2D Reconstructed Panoramic View- CBCT

C. Distance C: Superior Border of MF to Alveolar Crest (mm) - Oblique Coronal View- CBCT

D. Distance D: Inferior Border of MF to Base of Mandible (mm) - Oblique Coronal View- CBCT

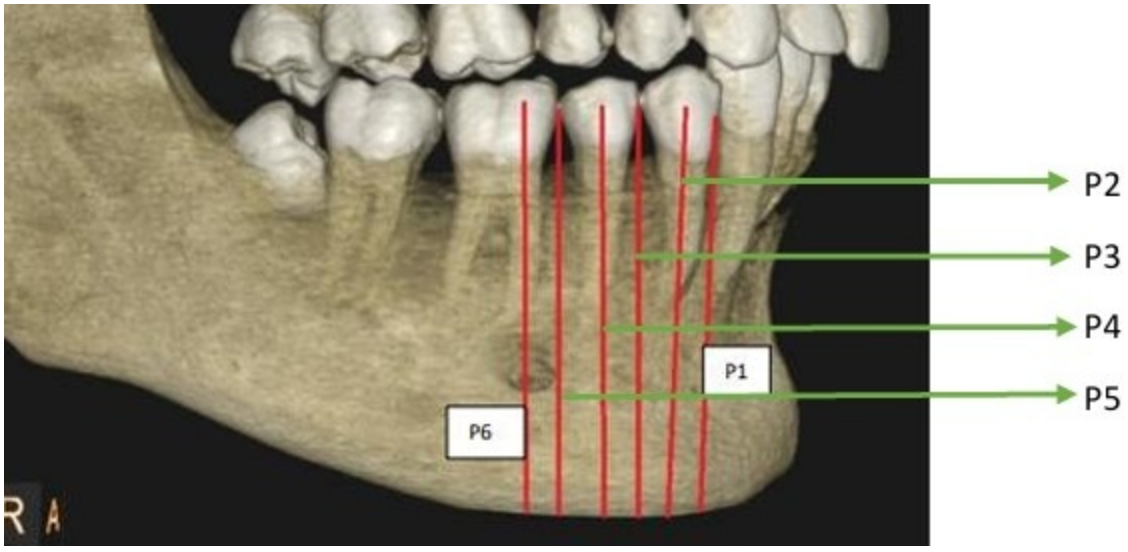


Figure 3

Position of Mental Foramen

P1: A vertical line drawn anterior to the long axis of the mandibular 1st premolar, P2: A vertical line aligned with the long axis of the root of the mandibular 1st premolar

P3: A vertical line positioned between the long axes of the roots of the mandibular 1st and 2nd premolars

P4: A vertical line following the long axis of the root of the mandibular 2nd premolar

P5: A vertical line placed between the long axes of the mandibular 2nd premolar and 1st molar

P6: A vertical line aligned with the long axis of the mesial root of the mandibular 1st molar

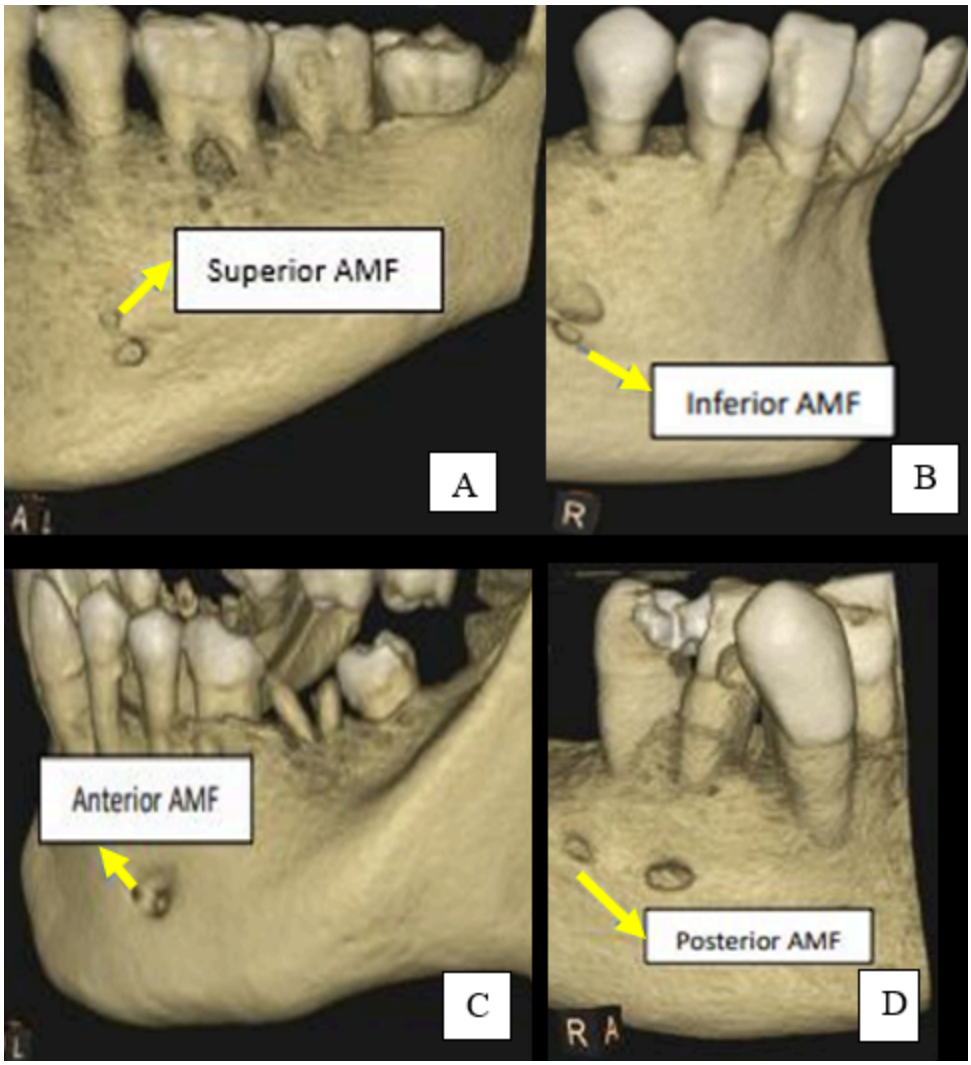


Figure 4

Location of Accessory Mental Foramen (AMF).

A. Superior AMF

B. Inferior AMF

C. Anterior AMF

D. Posterior AMF

E. CBCT-oblique / coronal view showing accessory Foramen (yellow arrow).

F. CBCT- Axial section view showing MF and AMF (yellow arrow).

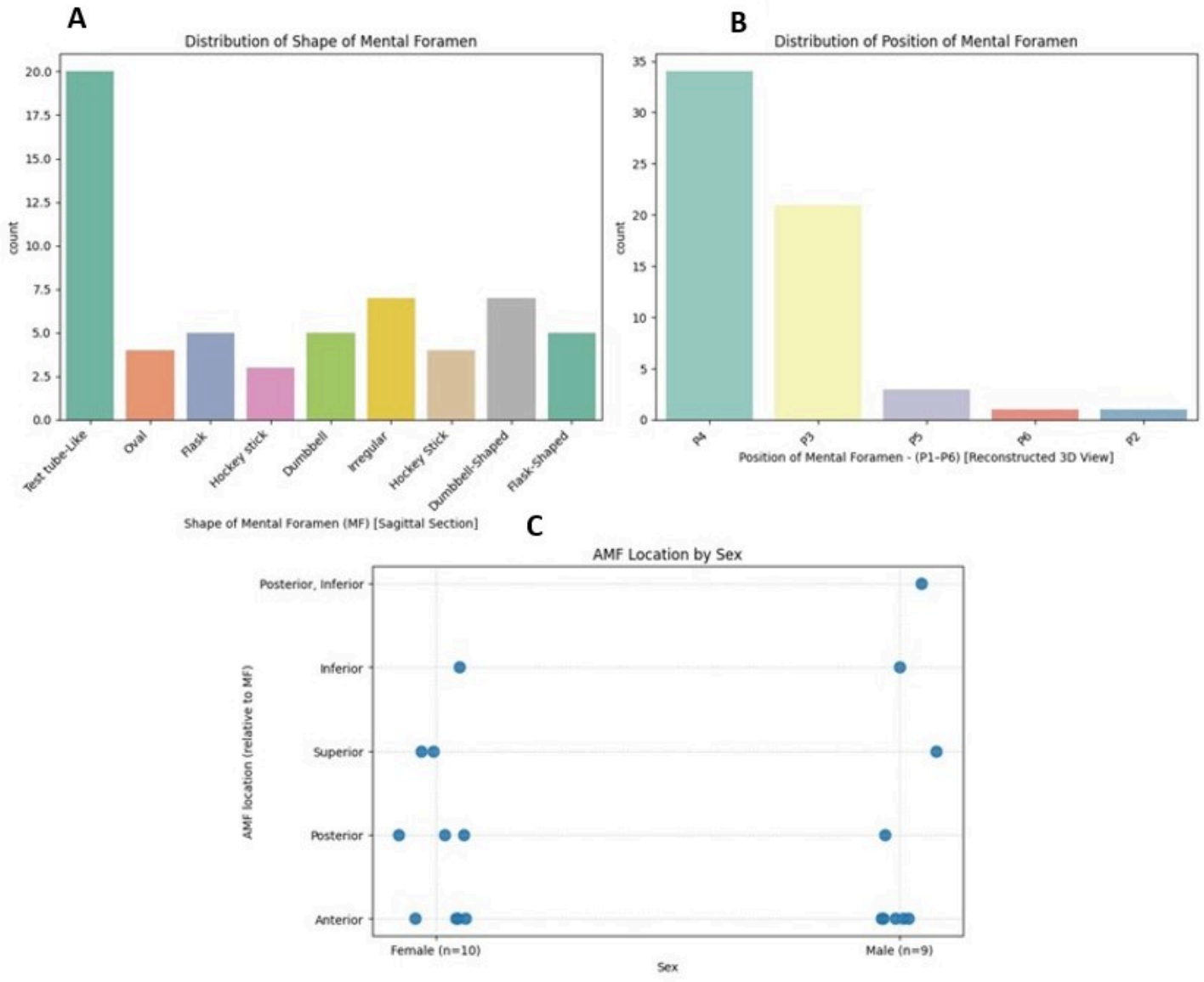


Figure 5

A. Distribution of shape of mental foramen. **B**. Distribution of the position of Mental Foramen, **C**. Distribution of Accessory Mental Foramen (AMF) by sex.

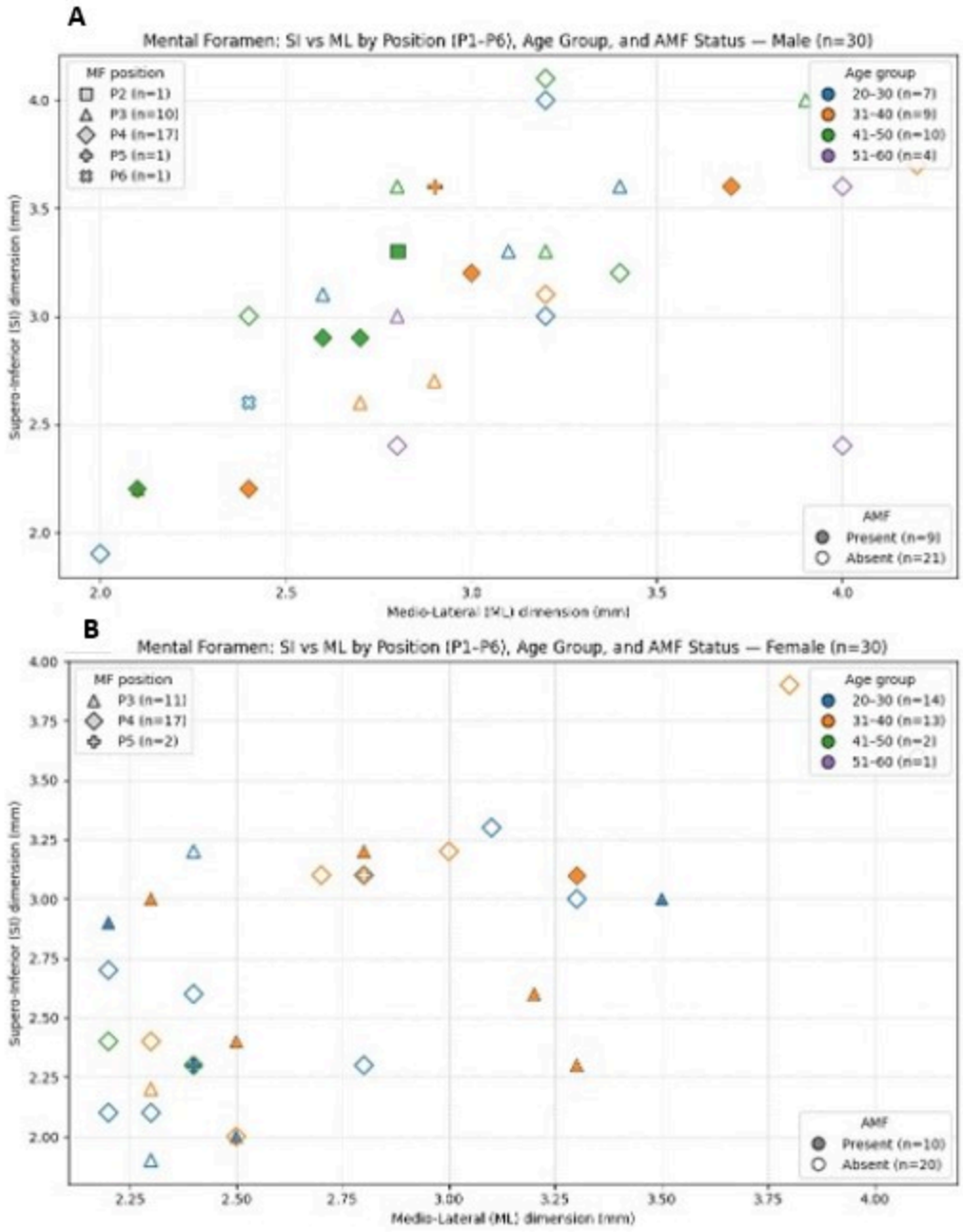


Figure 6

A.Mental foramen SI, ML, Position, age group, AMF status among Males. **B.**Mental foramen SI, ML, Position, age group, AMF status among females.

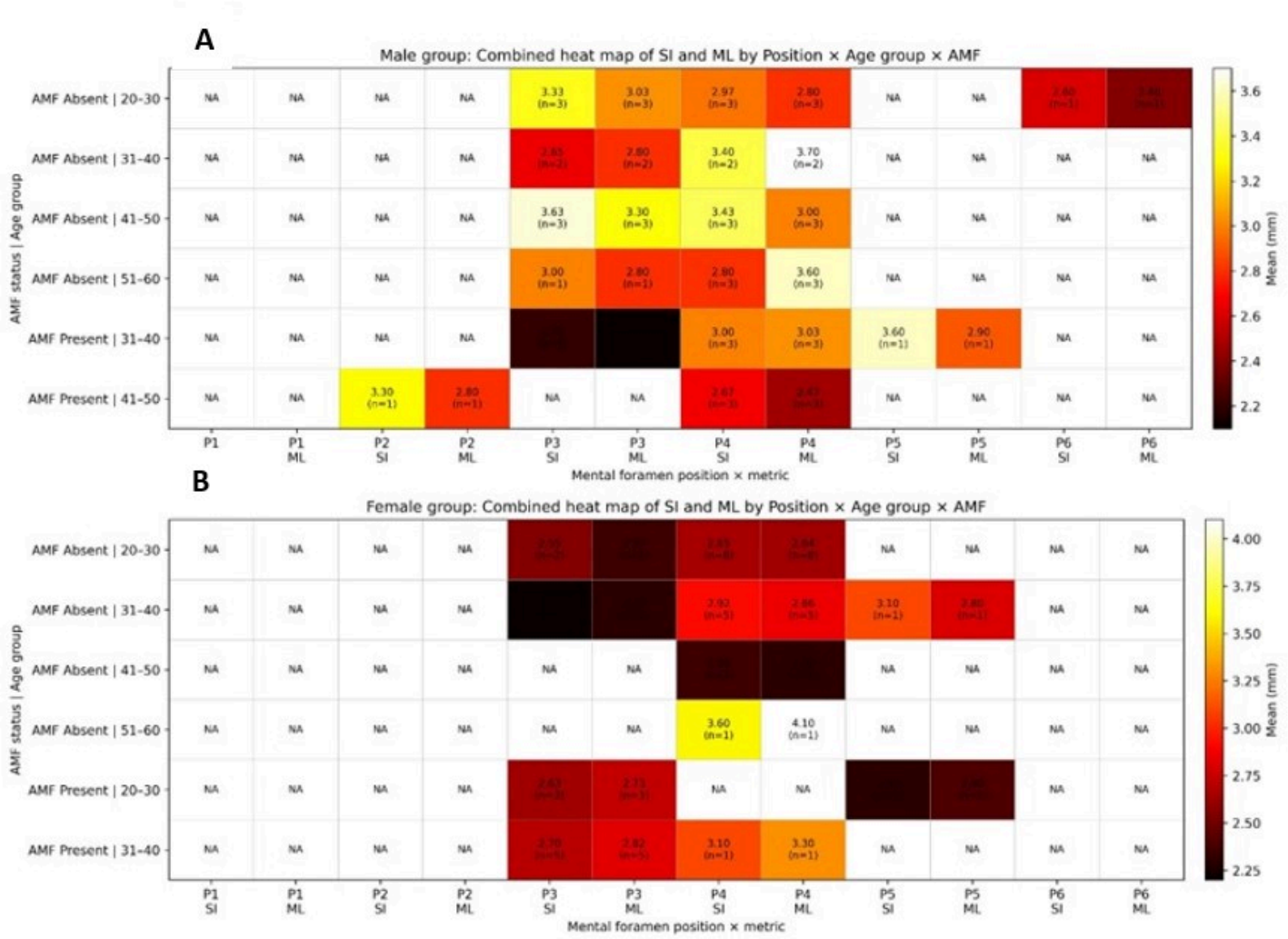


Figure 7

A. Combined heatmap of SI and ML dimension of MF by position, age group and accessory mental foramen among Males. **B**. Combined heatmap of SI and ML dimension of MF by position, age group and accessory mental foramen among Females