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Mental Foramen: A Comprehensive Review of the Distal Exit of the Mandibular Canal

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ABSTRACT

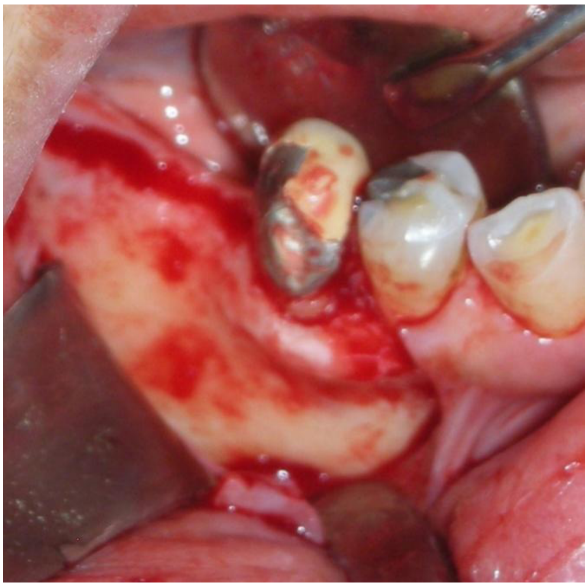
The mental foramen (MF), averaging 4.6 mm × 3.4 mm, is a vital anatomical landmark with significant implications for dental and surgical procedures. Its location, dimensions, and relationship to the inferior alveolar nerve (IAN) are critical in reducing complications such as nerve injury and treatment failure. A literature review of studies published between 1970 and 2024 explored the MF's anatomy, imaging, and clinical outcomes. This review examines variations in the MF's shape, size, number, and position, emphasising their clinical relevance. The MF may occasionally be radiographically or clinically absent and is not always a single opening. Understanding its variability is crucial for accurate localisation. This narrative review summarises that, despite an increasing amount of research, human variability influences the shape, size, and location of the mandible. Even within the same ethnicity, different studies have produced different locations and appearances in terms of its shape. Nevertheless, more Western studies generally reported the MF being located between the first and second premolars, and more Asian-centric studies reported it as closer to the second premolar. Accessory mental foramina (AMF), on the other hand, vary between ethnic groups, with a higher prevalence reported among non-Caucasians. Most AMFs were found to be unilateral, occurring more on the right side of the mandible. Bilateral AMFs have also been reported to range from 0% to 33.3%. On the contrary, MF may be missing in between 0.7% and 2.4% of the unilateral mandible.

Keywords: *Accessory mental foramen; inferior alveolar nerve; mental foramen; mental nerve; variations of the mental foramen*

INTRODUCTION

The sensation of the lower jaw is provided primarily by the third branch of the trigeminal nerve (V_3), the inferior alveolar nerve (IAN), which enters the mandibular canal through the mandibular foramen and emerges from the mental foramen (MF) as the mental nerve (MN) (Wadu *et al.*, 1997) (Fig. 1). The MN divides beneath the triangularis muscle into three branches: one descends to supply the skin over the chin, while two ascend to supply the skin and mucous membrane of the lower lip and gingiva of the lower incisor teeth to the mesiobuccal root of the mandibular first molar (Vayvada *et al.*, 2006). Hence, sensory changes to these structures usually indicate potential nerve injury following procedures performed in this region by dentists, maxillofacial surgeons, emergency physicians, and plastic reconstructive surgeons.

(a)



(b)

Fig. 1 (a) Reconstructed cone-beam computed tomography image of a mental foramen; (b) The mental nerve can be observed exiting the right mental foramen.

The MF is an indispensable landmark when carrying out MN blocks to facilitate the management of dental care, such as tooth extractions, root canal treatment, scaling and polishing, and treatment of gingival disease (Traxler *et al.*, 1992).

It is equally important for the injection of glycerol for the treatment of trigeminal neuralgia. In addition, locating the MF during complex procedures such as implant placement, periapical surgery/apicectomy, and orthognathic surgery is vital to avoid inflicting iatrogenic injury (Laher *et al.*, 2016). Complications related to these procedures may include local anesthetic toxicity from intravascular administration of the agent, inadequate anesthesia due to the wrong site of injection, hematoma formation, or paraesthesia along the MN distribution (Smith & Lung, 2006; Loudon, 2011). These scenarios may arise due to differences in the size, number, and location of the MF and variations in the patterns of branching of the MN. A comprehensive understanding of MF is paramount to identify and avoid it during surgery, hence avoiding iatrogenic injury to the nerve and associated structures.

A review of the literature on MF as observed via imaging was carried out in 2015, after which a substantial amount of data was published (Laher *et al.*, 2016). This current review aims to provide an up-to-date reappraisal, taking into account basic anatomy, procedural complications, hard and soft tissue relations, variations between population groups, asymmetry location, the presence of accessory foramina, and the use of various modalities to determine the location of the MF to provide a thorough understanding of this essential landmark.

MATERIALS AND METHODS

A comprehensive literature search was performed to identify relevant studies on the MF. The search was performed using the following electronic databases: PubMed, Scopus, Embase, the Cochrane Library, and ScienceDirect. The search strategy included keywords and Medical Subject Headings

(MeSH) terms. The key terms used were: "Mental foramen," "Accessory mental foramen," "Mental nerve," "Inferior alveolar nerve," "Variations of the mental foramen," and "Surgical relevance." Boolean operators ("and," "or," "not") were applied to refine the search results.

Studies were included in the review if they met the following criteria: published in English, peer-reviewed articles published between 1970 and 2024, addressing the subject of interest. Studies were excluded if they were non-English publications and non-peer-reviewed articles, such as editorials, letters, or conference abstracts. Of the 1,124 articles initially identified, 255 were selected based on title and abstract screening. This was followed by a full-text review of 143 articles, where 107 papers were included in the review after applying the selection criteria and reviewing the content of each article (Fig. 2). The screening and selection process involved all authors to minimise bias. Each author independently screened the titles and abstracts of the identified studies in the selection process. Data extraction involved categorising relevant information from the included studies, focusing on anatomical variations of the MF, the latest imaging findings, and their clinical relevance. This synthesised data was then analysed qualitatively to conclude from the existing literature.

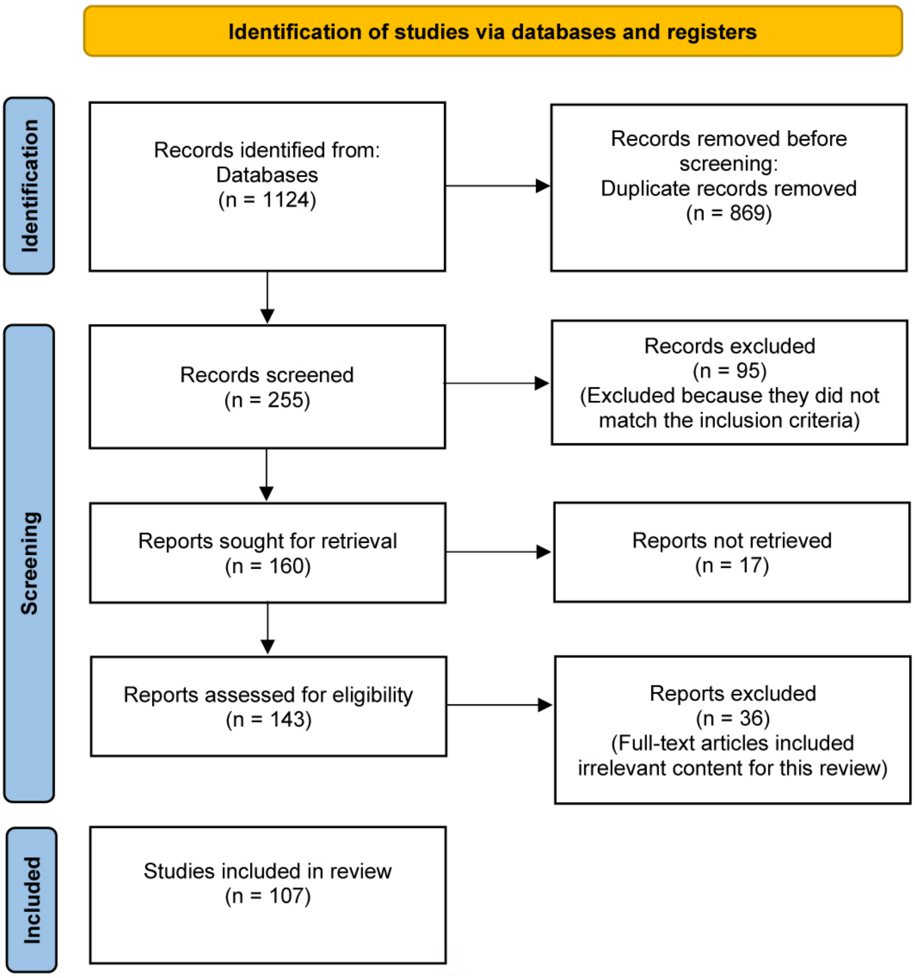


Fig. 2 Flowchart illustrating the literature search strategy.

MANDIBULAR CANAL AND THE INFERIOR ALVEOLAR NERVE

Presenting pertinent information regarding the mandibular canal is vital, considering its direct relationship to the MF, implying that variations in the anatomical presentation of the canal may influence the anatomy of the MF and its associated structures. The mandibular canal is described as a longitudinal passage oriented antero-inferiorly through the trabecular bone of the mandible and follows a curve of anterosuperior concavity in most cases (Lamas Pelayo *et al.*, 2008; Rashsuren *et al.*, 2014; Do *et al.*, 2020). At its distal end, it divides into an incisive canal continuing anteriorly to the incisive teeth and a mental canal running superolateral to the MF. This anatomy is subject to considerable variation, as reported by many authors. When a single mandibular canal is present, it may be any of four shapes: elliptical curve, linear curve, spoon-shaped curve, and turning curve in order of prevalence (Jung & Cho, 2014). The prevalence of these shapes is found to vary significantly, with the most common being the elliptical curve among Koreans (64.7%), while among the Iranians, it is reported that the linear curve is most frequently encountered (56.0%) (Jung & Cho, 2014; Nikkerdar *et al.*, 2022). Bifid mandibular canals have been previously described and are reported to have a prevalence ranging from 0.08% in the United States to 76.5% in a Turkish population group. Overall, the prevalence is an average of 18% (Samieirad *et al.*, 2023). Trifid canals are less common, with a prevalence ranging from 1.1% to 6.9% (Al-Siweedi *et al.*, 2023). In about 1% of cases, the accessory canals may open at the surface of the mandible distally, hence leading to the formation of accessory mental foramina (Ngeow & Chai, 2020; Valenzuela-Fuenzalida *et al.*, 2021). Studies employing cone-beam computed tomography (CBCT) scans to evaluate the mandibular canal have reported a higher prevalence of anatomical variations (25.0%) compared to panoramic radiographs (3.0%), suggesting that CBCT is a more reliable imaging modality for assessing the mandibular canal (Samieirad *et al.*, 2023).

Table 1 The shape of the mental foramen in different populations

Authors	Population	Shape of the mental foramen (%)		
		Oval	Round	Irregular
Gershenson *et al.* (1986)	Israelis	65.5	34.5	-
Agarwal & Gupta (2011)	Indians	92.0	8.0	-
Mbajiorgu *et al.* (1998)	Zimbabweans	56.3	43.8	-
Al-Khateeb *et al.* (2007)	Jordanians	45.0	45.0	10.0
Prabodha & Nanayakkara (2009)	Sri-Lankans	66.7	33.3	-
Oliveira Junior *et al.* (2009)	Brazilians	73.8	26.2	-
Singh & Srivastav (2010)	Indian	6.0	94.0	-
Budhiraja *et al.* (2012)	Indian	74.3	25.7	-
Mohamed *et al.* (2016)	Palestinians	8.3	51.6	40.1
Nikkerdar *et al.* (2022)	Iranians	74.3	25.7	-
Puri *et al.* (2020)	Indians	47.5	33.8	18.8
Taschieri *et al.* (2021)	Italians	51.1	42.0	-
AlQahtani (2022)	Saudi Arabians	28.0	66.6	5.3
Sheth *et al.* (2022)	Indians	66.0	31.0	-
Bahamid *et al.* (2023)	Saudi Arabians	36.7	5.0	58.3

The IAN traveling within the mandibular canal courses nearest the distal root tip of the third molar and is located furthest away from the mesial root tip of the first mandibular molar. In its distal aspect, the IAN gives off the incisive nerve before looping anterosuperiorly to emerge as the MN through the MF. This loop has been shown to have a prevalence of between 0% to 88%, with a length varying significantly between various studies, ranging from 2.0 mm to 7.3 mm without any noticeable gender dimorphism (Arzouman *et al.*, 1993; Neiva *et al.*, 2004; Wei *et al.*, 2020; Taschieri *et al.*, 2021; Othman & Zahid, 2022; Bahamid *et al.*, 2023). Studies relating to the MF confirm the existence of an incisive canal, a continuation of the mandibular canal. It may appear ill-defined on radiographs, which can predispose it to injury during procedures such as implant insertion, genioplasty, and bone harvesting in the anterior mandibular area in a region that was previously thought of as a 'safe zone' (Jacobs *et al.*, 2002; Uchida *et al.*, 2009; Sahman *et al.*, 2014; Ayesha *et al.*, 2019).

MENTAL FORAMEN

Shape of MF

The MF is a funnel-like opening that can be oval (Siddiqui *et al.*, 2011) or round in shape (Singh & Srivastav, 2010). Its average size is 4.6 mm horizontally and 3.4 mm vertically (Phillips *et al.*, 1990). A significant amount of variability exists regarding the shape of the MF (Fig. 1), which can either be oval, round, or irregular, as reported by numerous authors in various world regions. The oval shape is most prevalent among Indians, Saudi Arabians, Italians, Israelis, Zimbabweans, Sri Lankans, Brazilians, Nepalese, and Kosovians (Kqiku *et al.*, 2013; Kadel *et al.*, 2016; Puri *et al.*, 2020; Taschieri *et al.*, 2021; AlQahtani, 2022; Nikkerdar *et al.*, 2022). On the other hand, a high prevalence of the round shape is noted in Indians, Jordanians, and Palestinians (Sheth *et al.*, 2022). The Palestinians and Saudi Arabians also exhibit high occurrences of the irregular shapes (Bahamid *et al.*, 2023) (Table 1). In summary, even within the same ethnicity, findings may vary depending on the study locality.

Number of MF

There is usually a single MF on each side of the mandible. However, double or multiple MF have also been documented and are termed the accessory mental foramina (AMF) (Igarashi *et al.*, 2004; Prabodha & Nanayakkara, 2009; Haktanir *et al.*, 2010; Chrcanovic *et al.*, 2011). Human mandibles with more than one MF on either side are not a rare finding (Fig. 3).

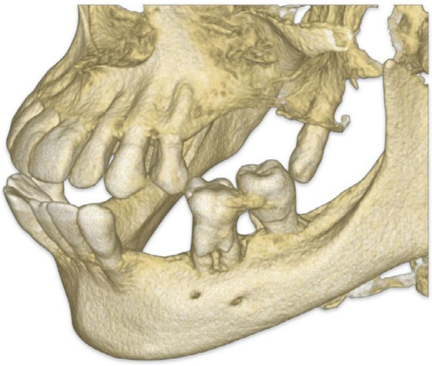


Fig. 3 A case with AMF. Image courtesy of Dr. Jimi Lie

Depending on the size of the multiple MF, the largest is usually considered the primary MF, while the rest are considered AMF. AMF has been reported to be present in 4% of human subjects (Haktanir *et al.*, 2010). Since the AMF has continuity with the mandibular canal and both vascular and neural structures pass through, it is just as important as the primary MF in dentoalveolar and maxillofacial surgery, especially when a flap needs to be raised. It is vital to know the presence of AMF in order to avoid complications such as post-surgical hypoesthesia due to nerve damage and haemorrhage (Naitoh *et al.*, 2011; Imada *et al.*, 2014). Previous studies have shown the prevalence of AMF to range from 1.0% to 26% among the populations studied (Sisman *et al.*, 2012; Kqiku *et al.*, 2013; Bosykh *et al.*, 2019). Examining 100 dried human skulls, a study reported an incidence of 5% and 8% of AMF on the right and left sides of the mandible, respectively. Additionally, the AMFs were usually smaller than MFs in size (Singh & Srivastav, 2010). AMFs vary between ethnic groups, with a higher prevalence reported among non-Caucasians (Sawyer *et al.*, 1998; Wei *et al.*, 2020; Ahmed *et al.*, 2021; Taschieri *et al.*, 2021; Nikkerdar *et al.*, 2022; Mallahi *et al.*, 2024) (Table 2).

Table 2 The prevalence of accessory mental foramen in different populations/races

Authors	Sample size	Study design	Accessory mental foramina frequency (%)				Bilateral (%)	Unilateral (%)	Left side (%)	Right side (%)
			One or more AMF	Single AMF	Double AMF	Triple AMF				
Gershenson *et al.* (1986)	575	DM	5.33	4.3	0.7	-	-	-	-	-
Shankland (1994)		-	6.62		-	-	-	-	-	-
Agthong *et al.* (2005)	110	-	1.8	1.8	-	-	-	-	-	-
Al-Khateeb *et al.* (2007)	860	DM	10	-	-	-	-	-	-	--
Katakami *et al.* (2008)	150	CBCT	10.6	10	0.6	-	0	100	-	-
Naitoh *et al.* (2009)	157	CBCT	7	3.5[a]	0.6[a]	-	18	82	40[a]	60[a]
Naitoh *et al.* (2011)	365	CBCT	7.7	3.1[a]	0.9[a]	-	7.1	92.9	-	-
Oliveira-Santos *et al.* (2011)	285	CBCT	9.4	-	-	-	-	-	-	-
Singh & Srivastav (2010)	100	DM	13	-	-	-	-	-	61.5	38.5
Gupta & Soni (2012)	120	DM	6.6	-	-	-	0	100	37.5	62.5
Kalender *et al.* (2012)	193	CBCT	11.9	11.9		-	17.4	82.6	-	-
Kokten *et al.* (2024)	45	DM	2.22	2.22	-	-	0	100	-	--
Kokten *et al.* (2024)	500	PR	<1	-	-	-	-	-	-	-
Sisman *et al.* (2012)	504	CT	1.9	-	-	-	30	-	40	30
Göregen *et al.* (2013)	315	CBCT	6.3	6.3	-	-	10	90	36.4	63.6
Udhaya *et al.* (2013)	90	DM	5.5	4.4	1.1	-	25	75	60	40
Han *et al.* (2014)	446	CBCT	8.1	-	-	-	8.3	-	36.1	55.5
Imada *et al.* (2014)	100	CBCT	3	3	-	-	33.3	66.7	50	50
Paraskevas *et al.* (2015)	96	DM	4.17	4.17		-	25	75	40	60
Wei *et al.* (2020)	306	CBCT	10.5	-	-	-	11.1	89.9	47.2	52.8
Taschieri *et al.* (2021)	65	CBCT	9.2	-	-	-	-	-	-	-
Ahmed *et al.* (2021)	306	CBCT	3.3	-	2.97	0.33	-	-	-	-
Nikkerdar *et al.* (2022)	378	CBCT	2.65	-	-	-	-	-	1.06	1.59
Mallahi *et al.* (2024)	178	CBCT	4.0	2.4	1.5	-	-	-	-	-

Note: CBCT – Cone beam computed tomography, DM – Dry mandible, PR – Panoramic radiography, CT – Computed tomography, AMF – Accessory mental foramina

Most AMFs were found to be unilateral, occurring on the right side of the mandible; indeed, out of 9 studies reporting the side on which the AMF was present, only 3 reported a higher prevalence on the left side of the mandible. Bilateral AMFs have also been reported to range from 0% to 33.3% (Gupta & Soni, 2012; Imada *et al.*, 2014). The presence of multiple foramina is not confined only to humans. In an anthropological study, Montagu found that orangutans exhibited the highest frequency of AMF, followed by gorillas and chimpanzees. Some existed as double foramina, but as many as five foramina had been observed (Mrożek *et al.*, 2020).

In addition, without a clear definition of AMF, Fuakami *et al.* (2011) described a few foramina being detected on the buccal surfaces of five Japanese cadaveric mandibles. Typically identified as nutrient foramina, these openings allow arteries to be distributed to the bone marrow and matrix. Although usually unconnected to the MF or mandibular canal, they found that one of their foramina was connected to the mandibular canal, and another was associated with a branch of the MN without a connection to the mandibular canal on CBCT images. The findings further confounded the true meaning of AMF. Hence, they proposed that these accessory buccal foramina (ABF) could possibly be: 1) a branch of the MN exiting the mandible, 2) a branch of the MN re-entering the mandible, and 3) a branch of the artery entering the mandible. Whether these foramina are individual variations or anatomical peculiarities, they are essential in the examination for treatment planning procedures involving the perimandibular regions (Fuakami *et al.*, 2011).

Serman (1989), on the other hand, described a distinct anatomical structure while examining 408 dry human mandibles. The undivided IAN coursed through the MF and only then divided into its terminal branches: the mental and incisive nerves. Interestingly, the incisive nerves re-entered the mandible through an anterior foramen below the incisor teeth. This foramen was proposed to be named the mandibular incisive foramen (Serman, 1989). It was suggested that separating the MN into several fasciculi earlier than the formation of the MF until the twelfth gestational week could be a reason for this phenomenon (Naitoh *et al.*, 2009). Clinically, a 'real' accessory foramen was discovered during endodontic surgery, as reported by Concepcion & Rankow (2000). While its significance in human evolution remains unknown, multiple foramina could clinically reduce the efficacy of local anaesthesia (Singh & Srivastav, 2010). A review of clinical cases showed that paraesthesia could occur if a large AMF were subjected to injury (Iwanaga *et al.*, 2015). If observed using conventional panoramic radiography, AMF could also be mistaken for a tumour (Gamoh *et al.*, 2014).

On rare occasions, the MF may be absent (de Freitas *et al.*, 1979; da Silva Ramos Fernandes *et al.*, 2011; Oliveira-Santos *et al.*, 2011; Matsumoto *et al.*, 2013; Lauhr *et al.*, 2015). However, a prevalence of 0.7% for unilateral missing MF has once been reported (Oliveira-Santos *et al.*, 2011). Using CBCT, the right and left MF of a 63-year-old Brazilian mother and her 27-year-old daughter were found to be absent and hypoplastic, respectively, without sensorial disturbances (da Silva Ramos Fernandes *et al.*, 2011). In a study that reviewed 169 dental panoramic tomograms of Malays, 8 cases were found with a missing MF on one side of the mandible, giving rise to a prevalence of 2.4% for this anomaly. However, no cases showed bilaterally missing MF (Ngeow & Yuzawati, 2003). A later study from Malaysia reported that up to 22.2% of absent MFs were attributed to non-visibility on panoramic tomograms owing to bone changes due to aging (Ngeow *et al.*, 2010).

Size of MF

The size of the MF (diameter) ranged from 2.08 ± 0.53 mm to 4.44 ± 1.13 mm in the articles assessed (Wei *et al.*, 2020; Ahmed *et al.*, 2021; Pelé *et al.*, 2021; Taschieri *et al.*, 2021; Nikkerdar *et al.*, 2022; Othman & Zahid, 2022; Mallahi *et al.*, 2024). On average, its diameter was approximately 3.2 mm and was generally greater among males compared to females (Naitoh *et al.*, 2009; Chen *et al.*, 2015; Muinelo-Lorenzo *et al.*, 2017; dos Santos Oliveira *et al.*, 2018; Goyushov *et al.*, 2018). In a study using multi-detector computed tomography (MDCT), it was reported that the diameter of the MF in their subjects was 2.6 mm (range 1.3 mm to 4.7 mm) (Haktanir *et al.*, 2010). In contrast, another study reported that the larger mean size for the MF was 3.0 mm in height (range 1.8 mm to 5.1 mm), and its length was 3.2 mm (range 1.8 mm to 5.5 mm) using CBCT (von Arx *et al.*, 2013). In a study comparing the Americans to Taiwanese, the diameters were 2.26 mm in Americans and 2.13 mm in Taiwanese, measured at the inferior alveolar canal level instead of the usual exit level (Chen *et al.*, 2013). Hence, there appears to be a difference in size due to gender and ethnic differences, besides being the result of different methods used to measure it. The MF of the modern human is significantly larger (on average 3.3 mm) in comparison to anthropoids such as the chimpanzee (2.1 mm) and gorilla (2.1 mm) (Corpas *et al.*, 2018).

Direction of MF Opening

The MF opens at the lateral surface in the body of the mandible in several manners: postero-superiorly in 68.7%, superiorly in 22.0%, laterally in 5.3%, anterior-superiorly in 2.6% and postero-anteriorly in 0.7% of patients. Similar ways the MF opens in the mandibles have also been found in apes in anthropological studies. Unlike other great apes, Montagu found that the gorilla resembled *Homo sapiens* more closely in how their MF opened in the mandible. This has raised concerns about the significance of the various directions of the

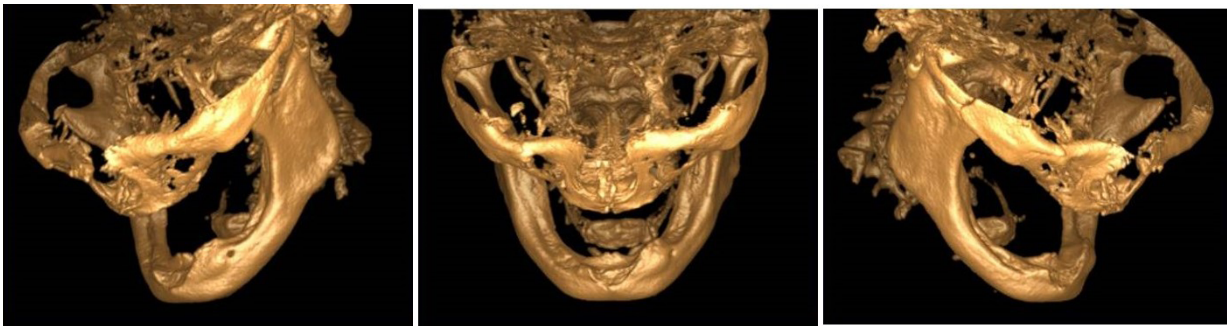


Fig. 4 The appearance of the mental foramen in a severely atrophied mandible. Note that the right mental foramen sits on the alveolar ridge.

opening of the MF in human evolution and its function in the growth and development of the mandible as a whole (Phillips *et al.*, 1990). Do note, however, that in the atrophic mandible, the MF may open on top of the alveolar crest (Fig. 4).

Position of MF

The position of MF in the mandible has been an area of extensive and intensive study. From clinical anatomy to sophisticated imaging techniques, investigators attempted to ascertain the precise location of the MF (Aminoshariae *et al.*, 2014). The textbook notion of the position of MF, which is described as commonly located between the apices of the mandibular premolars, had been misleading due to limited studies based on European populations (Green, 1987). Table 3 provides a summary of the location of the MF in various populations/ethnicities. The various locations of the MF will be discussed below based on clinical findings, cadaveric/dry skull investigations, and the use of different imaging modalities.

The position of the MF based on cadaveric studies

In a study aimed at providing clinicians with the safest and most effective site for botulinum toxin type A (BTX-A) injection, Hur *et al.* (2008) dissected 34 hemifaces of Korean adult cadavers of mixed gender. They found that the MF was mostly located in the middle third between the cheilion and the inferior border under the depressor anguli oris muscle (DAO). In addition, the MF was confined to the DAO muscle coverage. This has provided useful clinical references that ensure safe and effective injection of BTX-A and clinical facial skin landmarks to identify the position of MF (Hur *et al.*, 2008).

The position of the MF based on dry skulls

Many studies investigating the position of MF used dried human skulls/mandibles. In a study on dry mandibles, Kadel *et al.* (2016) reported that the vertical distances from the MF to the alveolar margin superiorly were 13.95 mm (right side) and 13.75 mm (left side), while the distance from the MF to the inferior border of the mandible was 12.24 mm (right side) and 12.26 mm (left side). Horizontally, the MF lay at 26.71 mm and 26.49 mm on the right and left sides, respectively, from the symphysis menti of the mandible. Additionally, the distance from the MF to the posterior border of the mandible was 65.34 mm on the right and 65.68 mm on the left side (Kadel *et al.*, 2016). Other studies on dry mandibles reported that the MF is between 19.0 mm and 29.0 mm from the symphysis. This distance is the lowest in Turkey (Yeşilyurt *et al.*, 2008) and the highest in Pakistani population groups (Rehman *et al.*, 2015).

Table 3 Variation of the location of the mental foramen among different populations/ethnicities

Authors	Population	Ethnicity	Modal location
Green (1987)	French	Chinese	Apical to first premolar
Moiseiwitsch (1998)	American		
Green (1987); Santini & Land (1990)	British		
Al-Khateeb *et al.* (1994)	Saudi Arabian* (Male)		
Aktekin *et al.* (2003)	Turkish*		
Santini & Land (1990); Kqiku *et al.* (2011, 2013)	European		
Ghandourah *et al.* (2023)	Saudi Arabian		
AlQahtani (2022)	Saudi Arabian	Caucasoid	
Luitel *et al.* (2020)	Saudi Arabian		Between first and second premolar
Bahamid *et al.* (2023)	Saudi Arabian		
Gherghiţă *et al.* (2021)	Romania		
Ahmad *et al.* (2024)	Saudi Arabia		
Taschieri *et al.* (2021)	Italians		
Puri *et al.* (2020)	Indians		
Haffaf *et al.* (2024)	Syrians		
Key *et al.* (2022)	Malays	Mongoloid	
Olasoji *et al.* (2004)	Northern Nigerian	Black	
Green (1987)	Australian aborigines	Australoid	
Moiseiwitsch (1998)	Americans*		
Green (1987)	British		
Green (1987)	Russian		
Al-Khateeb *et al.* (1994); Al Jasser & Nwoku (1998)	Saudi Arabian*	Caucasoid	
Abu-Ta'a *et al.*, (2023)	Palestinians		
Mashyakhy *et al.* (2021)	Saudi Arabian		
Gungor *et al.* (2006); Yeşilyurt *et al.* (2008)	Turkish*		
Chkoura & El Wady (2013)	Moroccan		
Rodríguez-Cárdenas *et al.* (2020)	Peruvian		
Chu *et al.* (2014)	Brazilian		
Green (1987); Santini & Land (1990); Santini & Alayan (2012)	Chinese		Apical to second premolar
Neo (1989); Shankland (1994); Santini & Alayan (2012)	Indians		
Fujita & Suzuki (2014)	Japanese	Mongoloid	
Kim *et al.* (2006)	Koreans		
Ngeow & Yuzawati (2003); Ngeow *et al.* (2010)	Malays		
Apinhasmit *et al.* (2006)	Thai		
Kadel *et al.* (2016)	Nepalese		
Sheth *et al.* (2022)	Indians		
Srivastava *et al.* (2024)	Indians		
Igbigbi & Lebona (2006)	Malawian		
Ukoha *et al.* (2013)	Southeastern Nigerians	Black	
Green (1987)	Africans		

Notes: *Some studies reported a modal location between the apices of the premolars, while others reported it to be apical to the second premolar

When relating to teeth present, an examination of 100 dried human skulls revealed that 68.8% of the MF in the Indian subjects was below the apex of the second premolar. Other positions that the MF had been found were between the first and second premolars (17.8%) and between the second premolar and first molar (11.5%) (Singh & Srivastav, 2010). Other investigators studying the position of MF in human skulls had recorded similar results. After investigating 87 human skulls, Green (1987) reported the most common position of the MF to be in line with the axis of the second premolar. In comparison, Miller reported the incidence of the position of MF in 75 Indian skulls to be below the apex of the second premolar (40%), between the first and second premolar (38%), between the second premolar and first molar (20%) and below the first premolar (3%) (Green, 1987). In Korean subjects, the location of MF was found to be below the second premolar (63.3%), between the first and second premolar (16.7%), below the first premolar (13.3%) and between the second and first molar (6.7%) (Hwang *et al.*, 2005). In another Asian study of Indian subjects, it was found that 75.36% of 138 mandibles showed that the MF was located directly below the second premolar (Shankland, 1994).

However, in a study of Caucasian skulls, the most common position of MF was between the apices of the premolars (58%) and below the apex of the second premolar (42%) (Neiva *et al.*, 2004). Other variations in the position of MF among Caucasians have long been recorded. Different results were obtained from studies using whole or hemimandibles. In a study of 75 dry human mandibles, Philips *et al.* (1990) found that 62.7% of the MF was located below the apex of the second premolar, 18.0% and 19.3% were mesial and distal to the apex of the second premolar, respectively (Phillips *et al.*, 1990). Additionally, 49.2% of MF in mixed dentate and edentulous Brazilian mandibles were found at the apex of the second premolar, and 2.34% could be found posteriorly on the mesial half of the first molar (Chrcanovic *et al.*, 2011). In another study, 44.08% and 46.23% of the 93 dry mandibles had MF located below the right and left second premolars, respectively, followed by, in descending order of frequency, between the premolars, anterior to first premolar, while the number of MF found between the premolars and below the first molar was the same, which were concordant with previous studies (Siddiqui *et al.*, 2011).

Position of the MF based on radiographic findings

Intra-oral periapical radiograph

Intra-oral periapical radiograph (IOPA) is still applicable and still relevant/accurate to be used to locate MF. However, there is a limitation of IOPA, among others, being unable to be placed low enough in patients with a small mouth/shallow floor of the mouth to be captured in the boundaries of the sensor. In addition, a limitation is the superimposition of the MF with apices of the premolar, either from the angulation employed or as a natural occurrence, resulting in confusion about the presence of a periradicular lesion in the premolar.

A detection rate of 46.8% using intra-oral periapical radiographs had been reported by Fisher *et al.* in 1976. The location of the MF was found as follows: between the premolars (70%), apex of second premolar (20.7%), distal to second premolar (6.8%), apex of first premolar (3.5%) and mesial to first premolar (0.9%) (Fishel *et al.*, 1976). In a multi-series study, Philips *et al.* (1992a; 1992b;) found that the corresponding position for 71% of MF located directly under the apex of the second premolar was 3.8 mm mesial to the apex of the premolar in the radiographs. They attributed this discrepancy to the distal curvature of the apex of the tooth and the funnel-like shape of the foramen, whose smallest diameter usually corresponded to the radiographic appearance. The detection rate in this study was 75%, and the reasons for non-detection were either because the MF was located below the edge of the films, multiple radiolucencies, masked by teeth, or angulation of the films (Philips *et al.* 1992b).

Panoramic radiographs

The radiographic discrepancy has also been reported in panoramic radiographs. Nevertheless, Kqiku *et al.* (2013) reported that the mean distance in the horizontal plane of the MF to the posterior border of the mandibular ramus was 67.5 mm and for the distance from the MF to symphysis menti 24.84 mm. In the vertical plane, the mean distance of the MF to the alveolar crest was 20.38 mm, and 14.68 mm for the MF's distance to the mandible's lower border. While the MF still appeared to be mesial to the apex of the second premolar on panoramic radiographs, the distance had shortened by 0.13 mm (Phillips *et al.*, 1992a; 1992b; Ghandourah *et al.*, 2023). Yosue & Brooks (1989a; 1989b), Pyun *et al.* (2013), and Gupta *et al.* (2015) reported similar findings.

Furthermore, other than locating MF mesial to the apex of the second premolar, Pyun *et al.* (2013) found that MF can also be seen distal to the root of the second premolar (26%), distal to the root of the first premolar (5%), and mesial to the root of the first molar (2%). In recent years, multiple studies have documented the position of the foramen on panoramic radiographs as being between the first and second premolar (Luitel *et al.*, 2020; Gherghiță *et al.*, 2021; AlQahtani, 2022; Bahamid *et al.*, 2023; Ahmad *et al.*, 2024).

In addition, four panoramic radiographic subtypes of MF were described (Yosue and Brooks, 1989a; 1989b,) namely:

a. Continuous type: the mental canal is continuous with the mandibular canal;
b. Separated type: the foramen is distinctly separated from the mandibular canal;
c. Diffuse type: the foramen is diffuse but with a distinct border of the foramen; and
d. Unidentified type.

Examining 245 orthopantomograms (OPGs), Gupta *et al.* (2015) reported that the most encountered type was continuous (37.3%), followed by separated (35.8%), diffuse (16.4%), and unidentified (10.5%). However, Kqiku *et al.* (2011) reported that the separated type was more common in Kosovians. Many panoramic radiograph studies revealed ethnic variation in the position of the MF, as shown in Table 3.

Detection of MF by panoramic radiographs is not always possible. Growing tooth buds, radiographic contrast, indistinguishable trabecular pattern, and thin mandibular bone are possible reasons for the non-detection of MF (Lim *et al.*, 2015). Nonetheless, when detected, the position of MF on panoramic radiographs is usually more consistent than periapical radiographs. This is probably due to the wide-angle view and vertical angulation of OPG. However, inherent in its system, adjusting the vertical and horizontal position of the mandible, increasing the film density and magnification of panoramic radiographs can all affect the position of MF (Yosue and Brooks, 1989b; Phillips *et al.*, 1992a; 1992b). Technical confounders aside, factors such as age, race, ethnicity, mesiodistal tooth size, proximal surface attrition, loss of teeth, and alveolar bone atrophy have all been reported to affect the position of MF (Ardakani & Azam, 2007; Ngeow *et al.*, 2010; Chrcanovic *et al.*, 2011; Siddiqui *et al.*, 2011).

Computed tomography/Cone-beam computed tomography

Recently, computed tomography (CT)/CBCT imaging techniques have been used to provide a similar accurate morphometric distance of the MF from the midline, besides delineating its relationship to the dentition present. In a study evaluating the MF in adult subjects, it was reported that MDCT can identify, localise, and characterise the MF. Its distance from the midline was 24.9 mm (range 19.6 mm to 29.8 mm), and from the alveolar ridge was 14.2 mm (range 10.7 mm to 20.5 mm) (Haktanir *et al.*, 2010).

The first description of the ability of CBCT to assess the IAN and MF occurred with the introduction of the new CBCT by NewTom-9000, Quantitative Radiology, Verona, Italy (Mozzo *et al.*, 1998). Its use should be coupled with good software to map the mandibular canal/MF, such as Slicer (Fedorov *et al.*, 2012).

Using CBCT, which provides less radiation exposure, von Arx *et al.* (2013) detected 56% of the MF to be located apically between the first and second premolars, and 35.7% was located below the second premolars. Additionally, the anterior loop was detected in 70.1% of the cases (von Arx *et al.*, 2013). On CBCT images of admixed subjects, Carruth *et al.* (2015) found 53.7% and 45.3% of the MF to be located on the mesial and distal of the apex of the second premolar, respectively. Only 1% of the cases corresponded to the apex of the second premolar. They also found that the distal horizontal distance from the cementoenamel junction was significantly greater in black than white subjects. Conversely, studies performed among the Indian, Peruvian, Saudi Arabian and Palestinian groups revealed that the majority of the foramen were positioned in line with the apex of the second premolar (Puri *et al.*, 2020; Rodríguez-Cárdenas *et al.*, 2020; Mashyakhy *et al.*, 2021; Sheth *et al.*, 2022; Abu-Ta'a *et al.*, 2023). Using CT scans to delineate the course of the mandibular canal, one study found that the IAN formed anterior loops in 36% of the cases. As it exited, the MF was positioned below the second premolar (56%), between the first and second premolar (24%), below the first premolar (16%), and between the second premolar and first molar (4%) (de Oliveira Júnior *et al.*, 2011).

The MF's anteroposterior and apicobasal morphometric measurements yielded a 0.5 and 0.27 ratio, respectively (Key *et al.*, 2022). Similar to the findings presented using panoramic radiographs, many CBCT studies have revealed ethnic variation in the position of the MF, as shown in Table 3.

Clinical significance of the MF

Diagnostic

Unilateral sensory neuropathy of the chin invariably indicates MN disturbances. Termed the Numb Chin Syndrome (NCS) or mental nerve neuropathy (MNN), it is a condition defined as an infrequently altered sensation characterised by hypoesthesia, paraesthesia, or thermalgesic anaesthesia of the skin of the chin and lower lip, confined to the regions innervated by the MN. Commonly, it is a benign condition caused by irritation from infected periapical areas on teeth near MF. In cases of MN paraesthesia due to microorganisms and microbial products of the infected tooth, administration of antibiotics and steroids followed by more definitive treatment such as root canal therapy or extraction of the offending teeth usually resolves this condition (Ngeow, 1998). As periapical radiographs are essential in the diagnosis and treatment of root canal therapy, the radiolucent appearance of the MF around the apex of the premolar region may be mistakenly interpreted as periapical pathoses or vice versa, and hence, complete medical history and a thorough examination are paramount to avoid diagnostic error (Morse, 1997; Ngeow, 1998). Conversely, pathology near the MF may be easily overlooked if it is assumed to be normal anatomy. Baskaran *et al.* (2006) reported a case of patient death in which an unsuspected high-grade lymphoblastic lymphoma presented as right chin numbness for several days, with no identifiable dental causes. Additionally, Bodner *et al.* (1987) reported a case in which NCS/MNN was associated with a compound odontoma. Removing the compound odontoma entirely resolved the situation. Therefore, in cases in which no dental cause can be found, more sinister causes should be sought after.

Injection of local anaesthesia and glycerol

Knowledge of the position of the MF can significantly affect the success of injections. The MF position can guide the administering either local anaesthesia for surgical procedures or glycerol in treating trigeminal neuralgia. As a general guide, Phillips *et al.* (1990) suggested that the needle should be oriented along the long axis of the second premolar at a point posterior and superior to the MF, located below the clinical crown, before being inserted into the soft tissue. This point is usually located 60% of the distance from the tooth's buccal tip to the mandible's inferior border. The needle should advance in an anterior and inferior direction until the funnel-like opening of the MF directs it into the mental canal, where the solution should be deposited (Phillips *et al.*, 1990). However, when repeated failures occur during injection, the racial differences in the position of the MF, as shown in Table 3, should be taken into consideration.

Implants

After implant placement, sensory disturbances in the lip, chin, gingival tissue, and tongue have been documented. Even though most patients recover within a year, the risk of persistent altered sensation for more than one year is 5% to 15% (Bartling *et al.*, 1999; Abarca *et al.*, 2006; Na *et al.*, 2019). Hence, establishing a safety zone for implant placement of at least 2 mm is essential. Before implant insertion, CBCT is required to assess the IAN and MF for diagnostic purposes. Once more clarity is obtained, the zone of safety between the implant and the coronal part of the nerve can be designated. However, if the presence of the anterior loop is suspected, or when the amount of bone present coronally to the nerve is unclear, the MF should be surgically probed. When the safety zone can be ascertained, the implants can be placed anterior to, posterior to, or above the MF. In cases where implants need to be placed deeper than the safety zone, the presence or absence of the anterior loop must be determined.

Flap design

When performed with an atraumatic flap for periapical surgery around the mandibular premolar area, a correctly designed flap retraction can significantly reduce the incidence of post-surgical paresthesia (Concepcion & Rankow, 2000) (Fig. 1b). A full trapezoidal or mini trapezoidal flap with a wide relieving incision away from the estimated site of MF is recommended. In this manner, the MN will be stretched within the flap bed while achieving adequate access to the operative site on teeth posterior to the MF without injuring the nerve. On the other hand, if a triangular flap has been decided, Moiseiwitsch (1998) recommended that a releasing incision of the surgical side be placed on the mesial line angle of the canine. This way, as with the trapezoidal flap, the MN will be protected within the bed of the flap without compromising access to the operative site. Similar good access to the operative site can be achieved with a distal releasing incision on the surgical site. This approach has the advantage of not reflecting the embedded MN at all. However, clinicians must be aware of the possibility of nerve damage if the incision is extended past the reflection of the buccal vestibule (Moiseiwitsch, 1998).

Prosthetic procedure

Alveolar ridge atrophy is a commonly observed clinical phenomenon. In edentulous patients, Chrcanovic *et al.* (2011) noted a change in the MF's height from the mandible's inferior border compared to that of dentated patients. In 447 OPGs of Iranian edentulous patients, as much as 49% of the cases showed that the MF was near the tip of the residual ridge (Ardakani & Azam, 2007; Chrcanovic *et al.*, 2011). In severely resorbed ridges, complete lower denture wearers often complained of discomfort when using the prosthesis. This could be due to the pressure of denture-bearing areas impinging on the IAN/MN, which was close to or even exposed to the surface covered only by a thin layer of mucous membrane (Wismeijer *et al.*, 1997; Akkitap & Gümrü, 2022) (Fig. 4). To rectify this, prosthodontists should be able to identify and locate the position of the MF and relieve the area with a layer of aluminium foil during denture construction (Wismeijer *et al.*, 1997). An unusual case of pain that results from nerve compression instead of numbness has been reported to occur in a patient having an implant-supported denture. The symptoms may be relieved by relieving the denture described above (Lim *et al.*, 2022).

Orthognathic surgery

Osteotomy of the anterior mandible is often involved in genioplasty to manipulate the shape and projection of the chin and lower face. Post-surgical sensory disturbances involving this area have frequently been reported (Lindquist

& Obeid, 1988; Nishioka *et al.*, 1988). Detailed knowledge of the course of IAN and the position of MF is essential to prevent post-surgical paraesthesia. Historically, the IAN was assumed to exit the mandible in a direct horizontal manner. However, studies have found that an anterior loop was formed prior to exiting the MF (Neiva *et al.*, 2004; Hwang *et al.*, 2005; de Oliveira Júnior *et al.*, 2011; von Arx *et al.*, 2013). A cadaveric study noted that, on average, the terminal mandibular canal could be located at 4.5 mm under the MF. Afterward, the nerve advanced 5.0 mm anteriorly, looped, and exited at MF. Surgeons are hence advised to keep the level of sliding osteotomy of the mentum at least 4.5 mm below the MF to avoid injury to the IAN (Hwang *et al.*, 2005).

CONCLUSION

When performing surgical procedures, clinicians must consider that the position of the MF may be influenced by ethnicity. From the review of studies on the location of MF, it would be highly probable that its position can be found below the second premolar for Asians primarily, while in Caucasoid population, it is predominantly located between the premolars. A small percentage of patients may have accessory MF, while another cohort may have missing MF. Understanding this would increase the success rate of dental/surgical treatment while minimising complications.

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