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Morphometric Variation of Mandibular Foramina with Related Accessory Foramina in Dry Adult Human Mandibles & it's Possible Clinical Significance

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ABSTRACT

Background: Mandibular Foramen (MF) serves as the passage for the inferior alveolar nerve and vessels, which traverse the mandibular canal and emerge as the mental nerve and vessels through the mental foramen. Accurate localization of the MF is crucial for effective local anaesthesia administration and successful mandibular implant placement in dental surgeries.

Aims and objective: To Determine the Clinical Significance of the Morphometric Variations of Mandibular foramina with related accessory foramina in Dry Adult Human Mandibles.

Methods: The descriptive cross-sectional study was conducted in 114 adult dry human mandibles of unknown sex and age collected from the bone bank of Anatomy Index Medical College, Hospital and Research Centre Indore MP, India. The damaged bones and those having pathological abnormalities were excluded from the study.

Results: Middle-aged to elderly group, with an average age of 44.61 ± 9.4 years; 30.7% were aged 40 or younger, while 69.3% were older than 40, with a male majority of 61.4%. Morphometric analysis indicated significant variability in mandibular foramen (MF) measurements, with key values like AB-MF at 17.04 mm (left) and 16.8 mm (right) and foramen width at 4.16 mm (left) and 3.97 mm (right). Comparative analysis showed significant right-left side differences in specific landmarks, notably AB-MF left ($p<0.001$).

Conclusion: Before lower jaw dental procedures such as osteotomy, orthognathic reconstruction surgeries of the mandible, and dental implant procedures, the exact location of the mandibular foramen is crucial for achieving a successful inferior alveolar nerve block and preventing damage to the neurovascular contents that pass through it.

Keywords: Mandible, Mandibular foramen, Mandibular notch, Accessory Mandibular foramen, Inferior alveolar nerve block;

Introduction:

Mandible is the longest, strongest, and lowest bone of the face and bears the lower teeth. The mandible consists of a 'U' shaped body which faces anteriorly with its two vertical rami facing posteriorly.

[i] Embryologically, body of mandible develops from fibrous mesenchymal tissue surrounding the Meckel's cartilage (cartilage of mandibular part, the first arch, is called Meckel's cartilage). The site of initial ossification as the primer for development of mandible has been called the mandibular primary growth center (MdPGC). The mandible is an important facial bone that helps in the activity of eating, speaking, and expressing feelings.[ii]

The mandibular foramen (MF) is an irregular foramen located a little above the centre of the medial surface of the mandibular ramus. To feed the mandibular teeth and contribute to the creation of the anterior loop, the inferior alveolar nerve and vessels split into mental and incisive branches after passing through the MF and the mandibular canal.[iii] One popular local anesthetic method in dentistry is inferior alveolar nerve block. However, it has been stated that this approach has a 20% to 25% failure rate.[iv] Inaccurate localization of M is the most frequent reason for inferior alveolar nerve block failure. The primary risks associated with this procedure are hemorrhage, neurovascular bundle damage, fractures, and mandibular ramus necrosis. Therefore, it is crucial to have a good understanding of the mandibular ramus.[v]

The medial side of the mandibular ramus contains the mandibular foramen. Its anteromedial boundary is protected by the lingula, a thin, pointed, triangular projection that resembles a tongue and attaches to the lower end of the sphenomandibular ligament from the spine of the sphenoid in the base of the skull.

It is oval or occasionally irregular in form.iii,vi The inferior alveolar nerve and vessels are transmitted by a canal that runs forward and downward from the mandibular foramen inside the mandibular ramus and body. The former is a branch of posterior division mandibular nerve, while the latter is a branch of first part of the maxillary artery and vein, which is a tributary of the maxillary vein.vi Inferior alveolar nerve, which is separated into mental and incisive branches, supplies the canine and incisor teeth in addition to the molar and premolar teeth.iii,vi

Accessory Mental Foramen (AMF) or Conduct of Serres refers to any aperture in the mandible that is not the mandibular foramen, tooth sockets, mental foramen, or lingual foramen.[vii] The AMF are observed commonly on the medial surface of ramus of mandible above or below the mandibular foramen.[viii] The AMF typically leads to the accessory mandibular canal, which may allow for the branching of mandibular nerves and vessels, including the facial nerve, mylohyoid nerve, buccal nerve, transverse cervical cutaneous nerve, inferior alveolar nerve, inferior alveolar vessels.v,vii The inferior alveolar nerve block may fail if anatomical variations of this nerve flow via these foramina and provide additional supply to the teeth in the lower jaw.[ix] Controlling intraosseous hemorrhage may become challenging if the auxiliary arteries inside them burst.ix Additionally, the AMF offers a simple path for infection and tumor cells to disseminate following radiation therapy.v,viii[x] Direct communication between mandibular cancellous bone and the periosteum and accessory foramina is possible. This might be a significant factor in bone invasion of the mandibular medial surface, particularly in those who have been exposed to radiation. This is explained by the fact that radiation therapy reduces the periosteum's capacity to serve as a barrier against the spread of a tumor.[xi] The AMF's anatomical existence may allow nerves and veins of the lower jaw and surrounding area to flow through uncommonly; as a result, it is clinically relevant in dentistry, surgery, anesthesia, and clinical procedures.

Accessory MF refers to any mandibular aperture that is not the MF, mental foramen, lingual foramen, or tooth sockets. The presence of auxiliary MF and additional branches of the inferior alveolar nerve may increase the failure rates of inferior alveolar nerve blocks since not all of the branches may be anesthetized.[xii] Additionally, following radiation therapy, malignancies from the mandibular lateral side have been reported to migrate to the accessory MF.v Therefore, radiotherapists need to be cognizant of auxiliary MF while planning radiation treatment in the lateral mandibular region. The AMF is therapeutically significant in dentistry, surgery, anesthesia, and clinical procedures because of its anatomical presence, which may permit rare passage of nerves and veins of the lower jaw and surrounding area. The current study was conducted to evaluate the morphometric variance of mandibular foramina and related auxiliary foramina in dry adult human mandibles and its possible clinical importance.

Aim: To find the Morphometric Variation of Mandibular foramina with related accessory foramina in Dry Adult Human Mandibles & it's Possible Clinical Significance

Material & Methods

The descriptive cross-sectional study was conducted in 114 adult dry human mandibles of unknown sex and age collected from the bone bank of Anatomy Index Medical College, Hospital and Research Centre Indore MP, India. Study would begin once permission was obtained from ethical committee. All the mandibles were undamaged with intact mandibular ramus along with mandibular foramina were enrolled in this study. Damaged bones and those having pathological abnormalities were excluded from the study. One individual used a digital vernier caliper and a magnifying glass to take all of the measurements. Vernier calipers, which were calibrated to 0.01mm precision with a range of 0-300mm and had 0% error, were used to measure location of mandibular foramens and the separation between each one concerning different landmarks in the mandibular ramus.

The following characteristics measured on both sides of mandible using sliding vernier calipers with an accuracy of 0.1 mm to properly pinpoint the mandibular foramen.

1) AB-MF: distance between the closest location on anterior border of mandibular ramus and midpoint of the anterior edge of mandibular foramen,
2) PB-MF: distance between the closest location on posterior border of mandibular ramus and the middle of the posterior edge of the mandibular foramen,
3) AB-PB: length of the ramus from the front to the back,
4) MF-MN: distance between the inferior limit of the mandibular foramen and the lowest point of the mandibular notch,
5) MF-MB: distance between the base of mandible & the inferior limit of the mandibular foramen,
6) III Molar-MF: the separation between the center of the third molar tooth or socket and the anterior margin of the mandibular foramen, and
7) RT-MF: distance between the tip of the retromolar trigone and the mandibular foramen.

The distance between the anterior border of the ramus and the midpoint of the mandibular foramen was determined by subtracting from AB-PB the sum of the distances AB-MF and PB-MF. This result yielded the width of the mandibular foramen, which was then divided in half to determine the midpoint of the mandibular foramen opening hole and added to distance AB-MF. The percentage that the distance between the anterior border of the ramus and the midpoint of the mandibular foramen represented the total width of the ramus (AB-PB) was then calculated. This was the quadrant where the mandibular foramen was located horizontally. The mandibular foramen's quadrant in anteroposterior placement was indicated by this value. The first quadrant had values between 0% and 25%, the second between 26% and 50%, the third between 51% and 75%, and the fourth between 76% and 100%. By determining the proportion of the sum of MF-MN and MF-MB distance that MF-MN represented, the quadrant on which the mandibular foramen was positioned was determined in the vertical direction.

Statistical Analysis:

Categorical variables are reported as continuous variables as the mean ± SD. Continuous variables were compared using paired samples *t*-test. All variables were tested to check the normal distribution of the data. The Pearson / Spearman correlation coefficients were employed for parametric and nonparametric variables to investigate the possible associations between right & left side parameters. P value <0.05 was considered a significance level.

Results:

The demographic analysis of 114 patients showed a predominantly middle-aged to elderly group, with an average age of 44.61 ± 9.4 years; 30.7% were aged 40 or younger, while 69.3% were older than 40, with a male majority of 61.4%. Morphometric analysis indicated significant variability in mandibular foramen (MF) measurements, with key values like AB-MF (Left: 17.04±3.02 mm, right: 16.8±2.87 mm), PB-MF (Left: 10.5±2.19 mm, right: 10.96±2.11 mm), AB-PB (Left: 31.73±4.43 mm, right: 31.53±3.53 mm), and foramen-width (Left: 4.16±0.61 mm, right: 3.97±0.56 mm). Additional measurements included MN-MF (Left: 20.42±5.34 mm, right: 18.91±4.55 mm), MF-MB (Left: 24.0±3.15 mm, right: 22.69±2.73 mm), III Molar-MF (Left: 22.39±4.19 mm, right: 21.3±3.81 mm), and RT-MF (Left: 14.86±5.22 mm, right: 13.0±4.12 mm). Notably, the left AB-MF showed a significant difference ($p<0.001$) with a mean difference of 0.20 mm. Additionally, significant differences were observed in Foramen-width Left ($p=0.001$, mean difference=0.19 mm), MN-MF Left ($p=0.019$, mean difference=1.51 mm), MF-MB Left ($p=0.001$, mean difference=1.39 mm), III Molar-MF Left ($p=0.041$, mean difference=1.0 mm), and RT-MF Left ($p=0.006$, mean difference=1.79 mm). However, non-significant differences found for PB-MF Left ($p=0.104$) and AB-PB Left ($p=0.668$). The 95% confidence intervals and standard errors indicate the precision of these estimates.

Correlation analysis showed weak to moderate, mainly non-significant associations, except for notable positive correlations like AB-PB-R and MF-MB-R ($r=0.218$, $p=0.020$). Symmetry was evident in MF size ($r=0.981$, $p=0.000$), suggesting strong bilateral consistency. Findings underscore complex anatomical relationships, with considerations for clinical implications based on sex, side, and symmetry in MF morphology.

Figure 1: Distribution of the studied patients based on age and gender

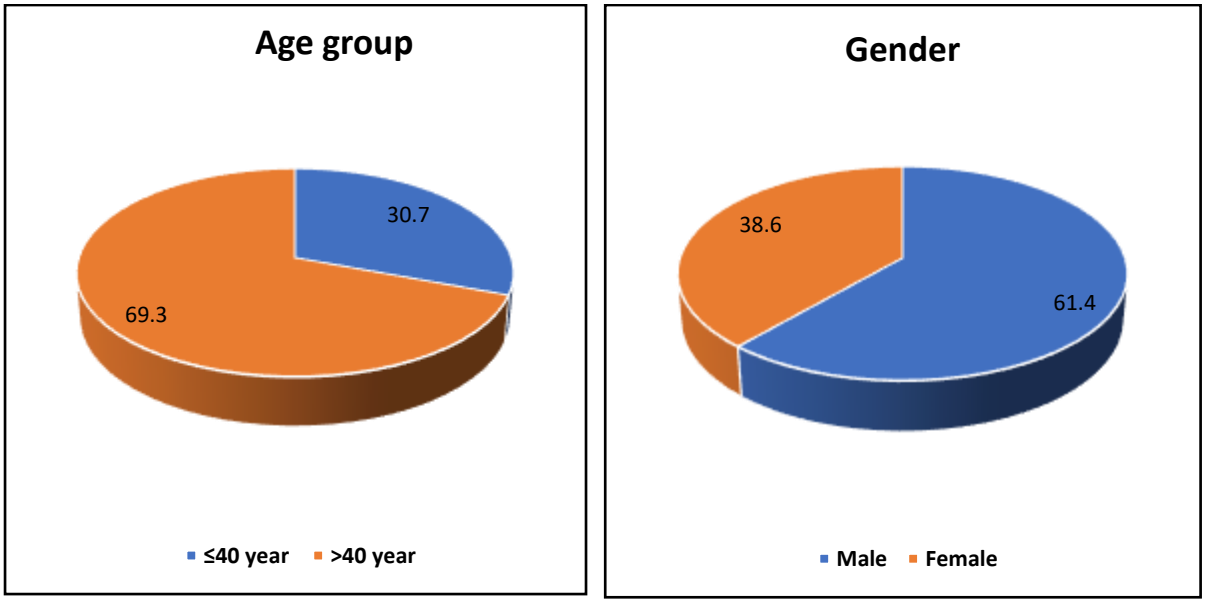

Table 1: Descriptive characteristics of the mean distance's mandibular foramen to various landmarks on mandible on each side

Measurement		Minimum	Maximum	Mean	Standard Deviation
AB-MF	Left	11.7	25.3	17.04	3.02
	Right	11.6	22.6	16.8	2.87
PB-MF	Left	7.0	16.0	10.5	2.19
	Right	7.0	16.2	10.96	2.11
AB-PB	Left	25.0	46.0	31.73	4.43
	Right	25.0	38.0	31.53	3.53
Foramen-width	Left	2.90	5.90	4.16	0.61

	Right	2.80	5.20	3.97	0.56
MN-MF	Left	11.0	29.0	20.42	5.34
	Right	11.0	27.0	18.91	4.55
MF-MB	Left	18.0	31.0	24.0	3.15
	Right	18.0	30.8	22.69	2.73
III Molar-MF	Left	15.0	29.3	22.39	4.19
	Right	15.0	29.0	21.3	3.81
RT-MF	Left	7.0	24.0	14.86	5.22
	Right	6.0	20.0	13.0	4.12

Table 2: Paired differences between the mean distances of mandibular foramen to various landmarks on mandible on each side

Measurement		**Mean difference**	**Standard Deviation**	**Std. Error Mean**	**95% Cl of Difference**		**p-value**
					Upper	**Lower**	
AB-MF	Left Right	0.20	0.58	0.54	0.99	0.31	<0.001
PB-MF	Left Right	-0.41	2.68	0.25	-0.90	0.08	0.104
AB-PB	Left Right	0.20	5.0	0.47	-0.73	1.14	0.668
Foramen-width	Left Right	0.19	0.59	0.05	0.08	0.30	0.001
MN-MF	Left Right	1.51	6.80	0.63	0.25	2.7	0.019
MF-MB	Left Right	1.39	4.34	0.40	0.58	2.19	0.001
III Molar-MF	Left Right	1.0	5.16	0.48	0.04	1.96	0.041
RT-MF	Left Right	1.79	6.8	0.64	0.52	3.06	0.006

Table 3: The correlation between left side and right side of mean distances mandibular foramen to various landmarks on mandible

		AB-MF-R	PB-MF-R	AB-PB-R	Foramen-width-R	MN-MF-R	MF-MB-R	Molar-MF-R	RT-MF-R
AB-MF-L	r - value	**0.981****	0.019	0.039	0.063	**-0.188***	0.081	0.042	-0.016
	p-value	**<0.001**	0.844	0.684	0.508	**0.045**	0.391	0.658	0.864
PB-MF-L	r - value	-0.062	**0.223***	0.010	0.025	-0.025	-0.038	-0.111	-0.008
	p-value	0.514	**0.017**	0.919	0.788	0.790	0.687	0.238	0.930

AB-PB-L	r - value	0.018	-0.081	**0.201***	0-.137	**0.195***	0.142	0.071	0.090
	p-value	0.846	0.391	**0.032**	0.147	**0.038**	0.131	0.454	0.341
Foramen-width-L	r - value	-0.034	0.065	0.022	**0.494****	-0.129	-0.024	0.023	-0.044
	p-value	0.719	0.493	0.814	**<0.001**	0.170	0.796	0.807	0.642
MN-MF-L	r - value	0.002	0.135	-0.022	-0.023	0.062	0.143	-0.098	0.158
	p-value	0.984	0.152	0.814	0.810	0.513	0.128	0.301	0.092
MF-MB-L	r - value	-0.005	0.031	-0.073	-0.102	0.017	-0.082	0.081	0.074
	p-value	0.954	0.741	0.438	0.282	0.858	0.387	0.389	0.436
Molar-MF-L	r - value	0.042	0.056	0.102	-0.099	-0.084	-0.001	0.169	-0.060
	p-value	0.659	0.554	0.280	0.296	0.373	0.994	0.072	0.529
RT-MF-L	r - value	-0.015	0.048	0.142	-0.051	0.063	0.159	0.101	-0.059
	p-value	0.876	0.612	0.131	0.590	0.508	0.091	0.283	0.532
*. Correlation is significant at the 0.05 level (2-tailed).									
**. Correlation is significant at the 0.01 level (2-tailed).									

Discussion:

For a descriptive cross-sectional study, 114 adult dried human mandibles of undetermined age and sex were extracted from the bone bank of Anatomy Index Medical College, Hospital and Research Centre Indore MP, India. Clean, dry mandibles with third molar tooth sockets are found in the anatomy department of Index Medical College, Hospital and Research Centre Indore MP, India. This investigation covered all entire and undamaged mandibular ramus and mandibular foramina. The study eliminated participants with pathological abnormalities and those with damaged bones. One individual used a digital vernier caliper and a magnifying glass to take all of the measurements. Vernier calipers, which were calibrated to 0.01mm precision with a range of 0-300mm and had 0% error, were used to measure location of mandibular foramens and the separation between each one concerning different landmarks in the mandibular ramus. Before taking each subsequent reading, the caliper's two jaws were pulled together until they touched, and the zero button was pressed. **Chaudhary S et al[ii], Shalini R et al[xiii], Padmavathi G et al[xiv], Kumar S et al[xv]** and **Gupta AK et al[xvi]** also opted similar methodology in their respective study.

In this study mean age of 44.61 ± 9.4 years. The age distribution showed that 30.7% (n=35) of patients were 40 years or younger, while 69.3% (n=79) were above 40 years. A predominantly male distribution, with 70 males (61.4%) and 44 females (38.6%).

In present study, we noted that the mean distances for various landmarks were: AB-MF (Left: 17.04±3.02 mm, right: 16.8±2.87 mm), PB-MF (Left: 10.5±2.19 mm, right: 10.96±2.11 mm), AB-PB (Left: 31.73±4.43 mm, right: 31.53±3.53 mm), and foramen-width (Left: 4.16±0.61 mm, right: 3.97±0.56 mm). Additional measurements included MN-MF (Left: 20.42±5.34 mm, right: 18.91±4.55 mm), MF-MB (Left: 24.0±3.15 mm, right: 22.69±2.73 mm), III Molar-MF (Left: 22.39±4.19 mm, right: 21.3±3.81 mm), and RT-MF (Left: 14.86±5.22 mm, right: 13.0±4.12 mm). The position of the mandibular foramen and its separations from several bone markers on South Indian-origin mandibles were examined in this study.

Table 4: Compare with the studies done in other parts of India

Authors (Years)	Country	Side	AB-MF	PB-MF	MN-MF	MF-IN
Samanta PP et al[xvii] (2013)	India	Right	15.72	13.29	22.7	--
		Left	16.23	12.73	22.27	--
Padmavathi G et al[xiv] (2014)	India	Right	16.8	11.7	22.0	25.0
		Left	16.9	12.1	22.6	24.8
Raghavendra VP & Benjamin W[xviii] (2015)	India	Right	16.21	11.08	21.38	--
		Left	16.67	11.11	20.95	--
Shalini R et al[xiii] (2016)	India	Right	17.11	10.47	21.74	--
		Left	17.41	9.68	21.92	--

Jain et al[xix] (2020)	Latvia	Right	16.88	12.31	17.41	19.80
		Left	17.33	11.75	18.01	20.11
Chimurkar Vilas et al[xx] (2020)	India	Right	17.58	13.61	19.54	26.86
		Left	17.22	13.30	19.84	27.31
Kaur R et al[xxi] (2022)	India (Punjab)	Right	16.41	13.51	23.44	23.85
		Left	16.18	14.16	23.05	24.81
Chaudhary S et al[xiii] (2023)	North India	Right	16.13	10.85	18.92	25.29
		Left	16.84	11.26	19.79	24.90
Present study	India	Right	17.04	10.50	20.42	24.00
		Left	16.80	10.96	18.91	22.69

According to **Samanta PP et al**xvii mandibular foramen was found to be 15.75±2.92 mm (R) and 16.23±2.88 mm (L) from anterior border, 13.29±1.74 mm (R) and 12.73±2.04 mm (L) from posterior border in a study of 60 mandibles from the northern region of India. Distances from mandibular notch were 22.7±3.0 mm (R) and 22.27±2.62 mm (L). Mandibular foramen was 21.54±2.92 mm (R) and 21.13±3.43 mm (L) away from the mandibular angle. **Shah K et al[xxii]** average distance between mandibular foramen and mandibular notch was 23–25 mm, 16–18 mm from the front border, 12–13 mm from posterior border, and 27–30 mm from the mandibular angle, according to a study done on 100 human mandibles from Ahmadabad. In study done on mandibles from South Indian population by **Varma LC et al[xxiii]**, the following observations were made. The average **Padmavathi G et al**[xiv] According to research on South Indian mandibles, the mandibular foramen is 16.9±2.5 mm (R) and 16.8±2.8 mm (L) from anterior border; 12.1±2.4 mm (R) and 11.7±2.0 mm (L) from posterior border; 22.3±3.4 mm (R) and 22.0±3.0 (L) from mandibular notch; & 22.2±2.9 mm (R) and 22.6±3.4 (L) from the mandibular angle. Notably, our investigation revealed a significant difference ($p<0.001$) with a mean difference of 0.20 mm in the left AB-MF. Foramen-width Left ($p=0.001$, mean difference=0.19 mm), MN-MF Left ($p=0.019$, mean difference=1.51 mm), MF-MB Left ($p=0.001$, mean difference=1.39 mm), III Molar-MF Left ($p=0.041$, mean difference=1.0 mm), and RT-MF Left ($p=0.006$, mean difference=1.79 mm) also showed significant differences. On other hand, AB-PB Left ($p=0.668$) and PB-MF Left ($p=0.104$) did not vary significantly. These results highlight significance of accurate measurements for clinical applications by illuminating the complexity and variety of mandibular anatomy. These results further emphasize how crucial it is to take into account landmark-specific and side-specific changes in mandibular morphology to make correct clinical evaluations.

Our study further noted that males had significantly larger PB-MF measurements on the right side ($p=0.024$), while III Molar-MF measurements were significantly larger on right side in males ($p=0.002$). No significant sex differences were found for AB-MF, AB-PB, Foramen-width, MN-MF, MF-MB, and RT-MF on both sides. However, some measurements showed trends towards sexual dimorphism. Specifically, males tended to have larger measurements than females for AB-MF, AB-PB, and MF-MB, while females had larger MN-MF measurements on left side. Standard deviations indicate individual variability. In a study from Pakistan by **Ansari AS et al[xxiv]** on 152 panoramic radiographs of mandibles, it was found that mean distance from mandibular foramen to anterior border was 17.69±0.61mm on right side, 17.65±0.63mm on left side in females and was 17.55±0.68mm on right side, 17.56±0.81mm on left side in males. From posterior border, it was 12.03±1.02mm on right side, 11.84±0.70mm on left side in females, and 12.66±1.23mm on right side, 12.52±1.84mm on left side in males. From mandibular notch, the distance was 20.51±0.92mm on right side, 21.03±0.90mm on left side in females and 20.45±1.02mm on right side, 21.28±0.85mm on left side in males. The values recorded present study on 100 mandibles in South-Indian population maintain bilateral symmetry which is parallel to other studies. The geographical difference in position MF was ruled out in this assessment by considering studies from South and North Indian population with present study. The reported accessory mandibular foramina are less. These findings suggest sex-specific and side-specific considerations may be relevant in certain clinical contexts.

This study noted the strong bilateral symmetry in mandibular foramen size. Complex anatomical relationships between mandibular foramina and adjacent structures. Importance of considering mandibular foramen shape, location, and size in clinical applications. Overall, this analysis provides insight into the intricate relationships between mandibular foramina and surrounding structures, informing clinical decision-making and anatomical education.

Limitation:

- A small sample of dry adult human mandibles might not be typical of the whole population.
- Study may not account for variations across different ethnicities, ages, or sexes.
- Potential for human error in morphometric measurements.
- Use of traditional measurement tools (e.g., callipers) may not provide precise measurements.

Conclusion

Accurate localization of the mandibular foramen is essential for effective inferior alveolar nerve blocks and to avoid neurovascular damage during lower jaw procedures such as osteotomy, orthognathic reconstruction, and dental implant surgeries. Accessory mandibular foramina could potentially facilitate the spread of tumor cells and infections. This morphometric study on the mandibular foramen and the prevalence of accessory foramina in the South Indian population provides valuable guidance for dental surgeons in planning and executing dental and maxillofacial procedures. Clinically, the distance between the accessory and primary mandibular foramina holds significance as it affects the distribution of local anesthetic, which depends on the anesthetic's type, concentration, and volume. This research is also beneficial for radiologists and oncologists in accurately identifying the mandibular foramen within the Indian demographic.

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