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Direct and imaging morphometry for the localization of the mandibular foramen (MF) in dentate and edentulous human subjects

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Abstract

Background: The mandibular foramen (MF) is the anatomic landmark where the inferior alveolar nerve enters the mandibular ramus, and the area of choice where anesthesia of this nerve is performed. The position of the MF can vary, and accurately establishing its location and topographic variations is of great importance for the successful anesthesia of the inferior alveolar nerve. **Materials and Methods:** We carried out two morphometric *ex vivo* studies concerning the topography of the MF, on dry human mandibles coming from dentate and completely edentulous human subjects of known age and gender and an *in vivo* morphometric study, through cone-beam computed tomography (CBCT) scans, concerning the topography of the MF in human subjects having Kennedy Class I mandibular edentulism. The morphological characteristics we investigated were: the distance between the MF and the anterior margin of the mandibular ramus (MF–AM distance), the distance between the MF and the posterior margin of the mandibular ramus (MF–PM distance), the distance between the MF and the inferior margin of the mandibular ramus (MF–IM distance), the distance between the MF and the temporal crest of the mandibular ramus (MF–TC distance), the distance between the MF and the superior margin of the mandibular ramus (MF–SM distance), and the vertical and transverse diameters of the MF. The results were statistically processed in Stata/MP13 software package using Student's *t*-test and two-way analysis of variance (ANOVA). **Results:** Through direct morphometry on dentate dry human mandibles, the MF–AM and the MF–SM distances showed statistically significant differences for age, gender and for interactions, while the MF–PM and MF–IM distances showed statistically significant differences for age and for interactions. In the case of the MF–TC distance, the only significant difference observed was for the gender. No statistical significance was found for side, age, gender, and interactions in the cases of MF vertical and transverse diameters. Through direct morphometry on completely edentulous dry human mandibles, the MF–PM and MF–SM distances showed statistically significant differences for age, gender and for interactions, while the MF–AM, MF–IM, and MF–TC distances, as well as the MF vertical and transverse diameters showed statistically significant differences for age and for model (interactions). The results showed that MF is 2 mm closer to the anterior margin of the mandibular ramus after having lost teeth. Through imaging morphometry, the MF–PM distance and the vertical diameter of MF showed statistically significant differences for age, gender and for interactions, while the MF–AM, MF–IM, MF–SM and MF–TC distances, as well as the transverse diameter of MF showed statistically significant differences for age and for interactions. Comparing the results obtained by the three studies, we found no statistically significant differences in relation to the gender of the subjects. The MF–IM and MF–TC distances and the transverse diameter of MF showed statistically significant differences for age, study and for interactions, while the MF–AM, MF–PM and MF–SM distances, as well as MF vertical diameter showed statistically significant differences only for age and for interactions. Morphological symmetry was demonstrated through our three studies, no statistically significant differences being determined in relation to side. **Conclusions:** The results of this research should increase the level of awareness among dentists with respect to MF topography changes with loss of teeth and help dental practitioners in refining the inferior alveolar nerve block techniques.

Keywords: inferior alveolar nerve, direct morphometry, imaging morphometry, CBCT scan, locoregional anesthesia.

Introduction

One of the two main anatomical landmarks where the trigeminal nerve enters the mandible is the mandibular foramen (MF), located on the mandibular ramus.

According to a study conducted by Buch (2011) [1], the term “mandibular foramen” is incorrect; it should instead be “inferior alveolar foramen”, in order to more adequately reflect its importance, because the inferior alveolar neurovascular bundle passes through the MF.

The MF is where the inferior alveolar nerve enters the mandibular ramus and where anesthesia of this nerve is performed in dentistry. A thorough understanding of MF and surrounding structures topography is of great importance for successful inferior alveolar nerve block, which is the procedure frequently used in dentistry for mandibular anesthesia [2]. Consequently, precise localization of the MF is a prerequisite for many successful dental treatments carried out in the lower jawbone: tooth extraction, dental implant placement, endodontic therapy,

tooth preparation for restorative purpose, dentoalveolar surgery, periodontal surgery, etc.

The position of the MF varies and depends on the dimensions of the mandibular ramus. Studies have shown the position of the MF varies from person to person, between different age groups in the same population, and even between the left and right sides of the same individual [3]. Scientific evidence also indicates that inferior alveolar nerve block has a higher failure rate than other anesthetic procedures carried out by the dentist [4]. Therefore, accurately determining the location of the MF and its topographic variations contributes to reducing failures and complications of the inferior alveolar nerve block [5–8].

Aim

This paper describes our personal research into the topography of the MF in Romanian population, completed through direct morphometry on human dry dentate and completely edentulous mandibles, and through imaging morphometry in dental patients with Kennedy Class I mandibular edentulism using cone-beam computed tomography (CBCT) data. The results of the study, that were statistically analyzed, present objective data supported by evidence concerning the topography of the MF. Data obtained from dentate, partially, and completely edentulous human mandibles are compared with each other and with the results of other recent studies found in the specialized literature. Standard anatomic landmarks have been established through our study, in order to precisely locate the MF and anesthetize the inferior alveolar nerve. Thus, potential complications resulting from morphological variations, could be avoided.

Materials and Methods

Two *ex vivo* morphometric studies concerning the topography of the MF were carried out on dry dentate and completely edentulous human mandibles, coming from human subjects of known age and gender.

An *in vivo* morphometric study concerning the topography of the MF was completed through CBCT scans, in partially edentulous human subjects (Kennedy Class I mandibular edentulism).

The following anatomic landmarks (as shown in Figures 1 and 2) were bilaterally used for morphometry:

- the distance between the MF and the anterior margin of the mandibular ramus (MF–AM distance) – 1;
- the distance between the MF and the posterior margin of the mandibular ramus (MF–PM distance) – 2;
- the distance between the MF and the temporal crest (internal oblique ridge) of the mandibular ramus (MF–TC distance) – 3;
- the distance between the MF and the inferior margin of the mandibular ramus (MF–IM distance) – 4;
- the distance between the MF and the superior margin of the mandibular ramus (MF–SM distance) – 5.

The vertical and transverse diameters of the MF were also bilaterally determined (Figures 3 and 4).

Figure 1 – MF topography on dry human mandibles. The anatomic landmarks used for the study. MF: Mandibular foramen.

Figure 2 – CBCT reformatted panoramic image: MF topography on a Kennedy Class I edentulous human mandible and measurements of the anatomic landmarks used for the study. CBCT: Cone-beam computed tomography; L: Left; MF: Mandibular foramen; R: Right.

Figure 3 – (a and b) CBCT: oblique multiplanar reformation through the mandibular ramus on the left mandible axial image; green line: MF horizontal diameter; yellow line: MF vertical diameter (patient with Kennedy Class I mandibular edentulism). CBCT: Cone-beam computed tomography; MF: Mandibular foramen.

Figure 4 – (a and b) CBCT: oblique multiplanar reformation through the mandibular ramus on the right mandible axial image; green line: MF horizontal diameter; yellow line: MF vertical diameter (patient with Kennedy Class I mandibular edentulism). CBCT: Cone-beam computed tomography; MF: Mandibular foramen.

Twenty-seven dentate dry human mandibles and 22 completely edentulous dry human mandibles, from the Francisc I. Rainer Anthropology Institute of the Romanian Academy, Bucharest were used for the *ex vivo* morphometric studies. The measurements were completed with a Workzone digital caliper (Globaltronics GmbH & Co. KG, Singapore).

Nineteen CBCT scans from partially edentulous (Kennedy Class I mandibular edentulism) patients of a private dental practice were used for the imaging morphometry. The study was conducted according to the current national legislation. Informed consent in written form was obtained from each patient for using the personal X-ray examinations in scientific research.

The machine used for the CBCT was a NewTom VGi Evo imaging unit, with the following technical parameters: 110 kV, 1–20 mA, between 3.5–4.3 seconds X-ray exposure time, the scanning process during a period of 18 seconds and the effective dose being around 100 μ SV. Data were processed using NNT ver. 11 software on a computer with the following specifications: Intel® Core™ i7 Processor, 16 GB System Memory, NVIDIA GTS 250 graphics card, Hard Disk 2 TB, Windows 10 Pro Operating System. The measurements expressed in millimeters, on mandibular sections, are at scale of 1:1 (Figures 2–4).

Both direct and radiographic measurements were statistically processed in Stata/MP13 software package using Student's *t*-test and two-way analysis of variance (ANOVA). A *p*-value ≤ 0.05 was considered statistically significant.

Results

The first study: direct morphometry on 27 dentate dry human mandibles

The distribution of the specimens with respect to gender shows that female mandibles accounted for 67% of the total specimens used for morphometry, but the only criterion for the selection of the dry mandibles was the presence of teeth.

The mean age of the 27 subjects was 29.2 ± 5.7 years, with a minimum age of 20 years and a maximum age of 39 years (Table 1). The analysis showed that the females were statistically significantly younger than the males ($p < 0.0022$).

Table 1 – Age of the subjects (direct morphometry on dentate dry human mandibles)

Gender	Age of the subjects [years]					
	N	Mean	SD	Median	Minimum	Maximum
Female	18	26.9	4.2	27.5	20	34
Male	9	33.7	5.7	35	21	39
Total	27	29.2	5.7	29	20	39

N: No. of subjects; SD: Standard deviation. Student's *t*-test: $p < 0.0022$.

The mean values on the left and right sides for the landmarks analyzed on dentate dry human mandibles are very close (Table 2), and this important finding shows there is morphological symmetry in what concerns the topography of the MF in the case of dentate mandibles.

The results of the morphological landmarks concerning the MF, for the 27 dentate dry human mandibles, were compared by side, gender, and age through the ANOVA multifactorial analysis (Table 3).

Table 2 – The results for the landmarks analyzed on dentate dry human mandibles, in relation to side

Direct morphometry on dentate dry human mandibles [mm]						
Right side – all specimens						
Analyzed landmarks	N	Mean	SD	Median	Minimum	Maximum
MF–AM distance	27	16.1	2.2	15.9	12	22.3
MF–PM distance	27	10.4	1.8	10.3	6.5	13.8
MF–IM distance	27	22.5	3.6	22.6	16.6	34.8
MF–SM distance	27	15.8	2.8	15.9	10.4	21.4
MF–TC distance	27	10.2	1.6	10.1	7.3	13.7
Vertical diameter of MF	27	7.9	2.2	7.4	4.9	12.1
Transverse diameter of MF	27	6.8	1.9	6.5	4	10.7
Left side – all specimens						
Analyzed landmarks	N	Mean	SD	Median	Minimum	Maximum
MF–AM distance	27	16.1	2.1	15.4	12.3	21.9
MF–PM distance	27	10.8	1.9	10.8	6.6	15
MF–IM distance	27	23.7	3.9	23.2	18	36.1
MF–SM distance	27	15	2.5	15.1	9.2	19.6
MF–TC distance	27	10.1	1.3	10.3	8.1	13.4
Vertical diameter of MF	27	8.5	2.5	7.6	4.7	13.7
Transverse diameter of MF	27	7.1	1.7	6.8	4	10.7

AM: Anterior margin of the mandibular ramus; IM: Inferior margin of the mandibular ramus; MF: Mandibular foramen; N: No. of subjects; PM: Posterior margin of the mandibular ramus; SD: Standard deviation; SM: Superior margin of the mandibular ramus; TC: Temporal crest (internal oblique ridge) of the mandibular ramus.

No statistical significance was found among both sides for any of the landmarks investigated, which is a sign of the presence of morphological symmetry. No statistical significance was found for side, age, and gender, including the model measuring interactions in the cases of MF vertical and transverse diameters. The MF–AM and the MF–SM distances showed statistically significant differences for age, gender and for interactions, while the MF–PM and MF–IM distances showed statistically significant differences for age and for model (interactions). In the case of the MF–TC distance, the only statistically significant difference observed was for the gender.

The second study: direct morphometry on 22 completely edentulous dry human mandibles

In this study, the distribution of specimens with respect to gender shows that female mandibles accounted for 59.09% of the total specimens used for morphometry on completely edentulous human mandibles, but the only criterion for the selection of the dry mandibles was all teeth lost.

In this case, the mean age of the 22 subjects was 71.4 ± 6.4 with a minimum age of 60 years and a maximum age of 81 years (Table 4). The subjects were much older than in the first study, and the women were statistically significantly older than the men ($p < 0.0018$).

The average measured values on the left and right sides are very close (Table 5), and this important finding means that there is morphological symmetry also in the case of edentulous mandibles.

Table 3 – The results of ANOVA multifactorial analysis concerning the landmarks analyzed on dentate dry human mandibles

Direct morphometry on dentate dry human mandibles							
ANOVA – multifactorial analysis							
Analyzed landmarks	N ₁	N ₂	R ²	Model (interactions)	Side	Gender	Age
				p	p	p	p
MF–AM distance	27	54	0.7609	<0.0001	0.9035	0.0375	0.0004
MF–PM distance	27	54	0.5391	0.0183	0.3640	0.4494	0.0119
MF–IM distance	27	54	0.7154	<0.0001	0.0926	0.3862	0.0015
MF–SM distance	27	54	0.6834	0.0001	0.1492	0.0483	0.0002
MF–TC distance	27	54	0.4799	0.0680	0.8503	0.0052	0.2538
Vertical diameter of MF	27	54	0.3892	0.2855	0.3749	0.3913	0.2870
Transverse diameter of MF	27	54	0.4210	0.1856	0.5895	0.4248	0.1379

AM: Anterior margin of the mandibular ramus; ANOVA: Analysis of variance; IM: Inferior margin of the mandibular ramus; MF: Mandibular foramen; N₁: No. of subjects; N₂: No. of findings; PM: Posterior margin of the mandibular ramus; R²: Coefficient of determination; SM: Superior margin of the mandibular ramus; TC: Temporal crest (internal oblique ridge) of the mandibular ramus.

Table 4 – Age of the subjects (direct morphometry on completely edentulous dry human mandibles)

Age of the subjects [years]						
Gender	N	Mean	SD	Median	Minimum	Maximum
Female	13	74.7	5.4	76	65	81
Male	9	66.6	4.5	66	60	75
Total	22	71.4	6.4	71	60	81

N: No. of subjects; SD: Standard deviation. Student's *t*-test: *p* < **0.0018**.

Table 5 – The results for the landmarks analyzed on completely edentulous dry human mandibles, in relation to side

Direct morphometry on completely edentulous dry human mandibles [mm]						
Right side – all specimens						
Analyzed landmarks	N	Mean	SD	Median	Minimum	Maximum
MF–AM distance	22	13.9	2.4	14.3	8.7	17.6
MF–PM distance	22	10	3.3	9.4	5.3	20.3
MF–IM distance	22	22.1	4	22	8.7	28.1
MF–SM distance	22	14.7	2.5	15.4	9.2	20.5
MF–TC distance	22	9.8	1.7	10.1	7.1	12.2
Vertical diameter of MF	22	8.5	2.9	7.9	3.2	13.3
Transverse diameter of MF	22	6.9	1.6	6.6	2.5	9.6

Direct morphometry on completely edentulous dry human mandibles [mm]

Left side – all specimens						
Analyzed landmarks	N	Mean	SD	Median	Minimum	Maximum
MF–AM distance	22	14.6	2.6	15.1	8.6	18.7
MF–PM distance	22	10.6	3.4	9.7	6.1	21.9
MF–IM distance	22	22.5	4.2	22.7	8.1	28.1
MF–SM distance	22	14.4	2.5	14.2	9.7	22.3
MF–TC distance	22	10	1.9	10.2	6.9	13.4
Vertical diameter of MF	22	9	3	9.1	2.4	13.7
Transverse diameter of MF	22	6.8	2	7.4	2.2	10.1

AM: Anterior margin of the mandibular ramus; IM: Inferior margin of the mandibular ramus; MF: Mandibular foramen; N: No. of subjects; PM: Posterior margin of the mandibular ramus; SD: Standard deviation; SM: Superior margin of the mandibular ramus; TC: Temporal crest (internal oblique ridge) of the mandibular ramus.

The measured values are relatively similar to those presented in the first study, with the MF–AM distance being smaller in the second study, but the difference is not too great: 16.1 vs. 14.2 mm. Therefore, the MF is 2 mm closer to the anterior margin of the mandibular ramus after having lost teeth.

The results of the investigated morphological landmarks concerning the MF, for the 22 completely edentulous mandibles, were compared by side, gender, and age through the ANOVA multifactorial analysis (Table 6).

Table 6 – The results of ANOVA multifactorial analysis concerning the landmarks analyzed on completely edentulous dry human mandibles

Direct morphometry on completely edentulous dry human mandibles							
ANOVA – multifactorial analysis							
Analyzed landmarks	N ₁	N ₂	R ²	Model (interactions)	Side	Gender	Age
				p	p	p	p
MF–AM distance	22	44	0.6213	0.0169	0.2560	0.4666	0.0118
MF–PM distance	22	44	0.8975	<0.00001	0.1844	0.0005	<0.00001
MF–IM distance	22	44	0.9343	<0.00001	0.4087	0.1353	<0.00001
MF–SM distance	22	44	0.6809	0.0033	0.5262	0.0109	0.0021
MF–TC distance	22	44	0.7350	0.0005	0.4987	0.2419	0.0007
Vertical diameter of MF	22	44	0.6960	0.0020	0.4678	0.5224	0.0012
Transverse diameter of MF	22	44	0.7741	0.0001	0.8923	0.2120	0.0001

AM: Anterior margin of the mandibular ramus; ANOVA: Analysis of variance; IM: Inferior margin of the mandibular ramus; MF: Mandibular foramen; N₁: No. of subjects; N₂: No. of findings; PM: Posterior margin of the mandibular ramus; R²: Coefficient of determination; SM: Superior margin of the mandibular ramus; TC: Temporal crest (internal oblique ridge) of the mandibular ramus.

No statistical significance was found among both sides for any of the anatomic landmarks investigated, which indicates the existence of morphological symmetry. The MF–PM and MF–SM distances showed statistically significant differences for age, gender and for interactions, while the MF–AM, MF–IM and MF–TC distances, as well as the MF vertical and transverse diameters showed statistically significant differences for age and for model (interactions) in the case of completely edentulous mandibles.

The third study: imaging morphometry through CBCT scans of the MF in 19 dental patients with Kennedy Class I mandibular edentulism

In this study, the proportion of male patients is higher, being of 57.89%. The only criterion for patient selection was the pattern of tooth loss (Kennedy Class I mandibular edentulism).

In the third study, the mean age of the 19 patients was 58.6±11.6 years, with a minimum age of 34 years and a maximum age of 81 years (Table 7), with no statistically significant differences by gender ($p=0.8761$).

Table 7 – Patients' age (imaging morphometry in patients with Kennedy Class I mandibular edentulism)

Patients' age [years]						
Gender	N	Mean	SD	Median	Minimum	Maximum
Female	8	58.1	11.1	57.5	45	79
Male	11	59	12.4	58	34	81
Total	19	58.6	11.6	58	34	81

N: No. of patients; SD: Standard deviation. Student's *t*-test: $p<0.8761$.

The mean values for the studied landmarks are very close on the left and right sides (Table 8), and this is an important remark which illustrates the existence of morphological symmetry in the case of partially edentulous mandibles (Kennedy Class I mandibular edentulism), as well.

These values are similar to those found in the first study, with only the results concerning the diameters of the MF being smaller than in the first two studies.

The results of the morphological landmarks concerning the MF measured by imaging morphometry, for the 19 partially edentulous mandibles (Kennedy Class I mandibular

edentulism) were assessed by side, gender, and age through the ANOVA multifactorial analysis (Table 9).

In this case, too, no statistical significance was found among both sides for any of the anatomic landmarks investigated, which is an evidence for morphological symmetry. The MF–PM distance and the vertical diameter of MF showed statistically significant differences for age, gender and for interactions (model), while the MF–AM, MF–IM, MF–SM and MF–TC distances, as well as the transverse diameter of MF showed statistically significant differences for age and for model (interactions).

Table 8 – The results for the landmarks analyzed in patients with Kennedy Class I mandibular edentulism, in relation to side

Imaging morphometry through CBCT scans of the MF in patients with Kennedy Class I mandibular edentulism [mm]

Right side – all patients						
Analyzed landmarks	N	Mean	SD	Median	Minimum	Maximum
MF–AM distance	19	14.7	1.8	14.9	10.2	17.1
MF–PM distance	19	9.6	1.7	9.7	6.3	12.2
MF–IM distance	19	25.8	3.2	25.7	20.6	34.8
MF–SM distance	19	16.4	2.2	15.5	12.9	20.5
MF–TC distance	19	11.7	1.9	12.3	6.3	14.1
Vertical diameter of MF	19	6.4	1.3	6.3	4.8	9.6
Transverse diameter of MF	19	3.9	1.5	3.3	2.1	7.3
Left side – all patients						
Analyzed landmarks	N	Mean	SD	Median	Minimum	Maximum
MF–AM distance	19	14.9	1.8	14.7	11.7	18.9
MF–PM distance	19	9.6	1.9	9.2	6.3	13.2
MF–IM distance	19	26.2	4.2	26.5	14.5	33.9
MF–SM distance	19	16	2.7	15.6	11.4	21
MF–TC distance	19	11.9	1.9	12.3	7.4	15.3
Vertical diameter of MF	19	6.3	1.7	6.6	2.7	10.8
Transverse diameter of MF	19	3.6	1.2	3.3	2.1	6.3

AM: Anterior margin of the mandibular ramus; CBCT: Cone-beam computed tomography; IM: Inferior margin of the mandibular ramus; MF: Mandibular foramen; N: No. of patients; PM: Posterior margin of the mandibular ramus; SD: Standard deviation; SM: Superior margin of the mandibular ramus; TC: Temporal crest (internal oblique ridge) of the mandibular ramus.

Table 9 – The results of ANOVA multifactorial analysis concerning the landmarks analyzed by imaging morphometry in patients with Kennedy Class I mandibular edentulism

Imaging morphometry through CBCT scans of the MF in patients with Kennedy Class I mandibular edentulism							
ANOVA – multifactorial analysis							
Analyzed landmarks	N ₁	N ₂	R ²	Model (interactions)	Side	Gender	Age
				<i>p</i>	<i>p</i>	<i>p</i>	<i>p</i>
MF–AM distance	19	38	0.9177	<0.00001	0.5622	0.2668	<0.00001
MF–PM distance	19	38	0.8623	0.0002	0.8152	0.0177	0.0009
MF–IM distance	19	38	0.8603	0.0002	0.5253	0.3254	0.0002
MF–SM distance	19	38	0.8034	0.0029	0.4885	0.1695	0.0021
MF–TC distance	19	38	0.9700	<0.00001	0.2133	0.9999	<0.00001
Vertical diameter of MF	19	38	0.8515	0.0004	0.5904	0.0022	0.0003
Transverse diameter of MF	19	38	0.8418	0.0006	0.3219	0.8497	0.0004

AM: Anterior margin of the mandibular ramus; ANOVA: Analysis of variance; CBCT: Cone-beam computed tomography; IM: Inferior margin of the mandibular ramus; MF: Mandibular foramen; N₁: No. of patients; N₂: No. of findings; PM: Posterior margin of the mandibular ramus; R²: Coefficient of determination; SM: Superior margin of the mandibular ramus; TC: Temporal crest (internal oblique ridge) of the mandibular ramus.

Comparison of data obtained from all three studies

Comparing by the ANOVA multifactorial analysis the data concerning the MF, obtained in all three studies for 68 subjects (Table 10), no statistical significance was found among both sides for any of the morphometrical parameters investigated, which reveals morphological symmetry.

Table 10 – Results of ANOVA multifactorial analysis when comparing the three studies

Morphometry of the MF – comparing the data obtained from all three studies								
ANOVA – multifactorial analysis								
Analyzed landmarks	N_1	N_2	R^2	Model (interactions)	Study	Side	Gender	Age
				p	p	p	p	p
MF–AM distance	68	136	0.7239	<0.00001	0.1281	0.2836	0.6526	<0.00001
MF–PM distance	68	136	0.7260	<0.00001	0.8819	0.2507	0.7185	<0.00001
MF–IM distance	68	136	0.8159	<0.00001	<0.00001	0.0725	0.7863	<0.00001
MF–SM distance	68	136	0.6643	<0.00001	0.0526	0.1223	0.5619	<0.00001
MF–TC distance	68	136	0.7298	<0.00001	0.0022	0.6023	0.2894	<0.00001
Vertical diameter of MF	68	136	0.6205	<0.00001	0.1146	0.3365	0.7647	0.0004
Transverse diameter of MF	68	136	0.7490	<0.00001	<0.00001	0.9586	0.6367	0.0001

AM: Anterior margin of the mandibular ramus; ANOVA: Analysis of variance; IM: Inferior margin of the mandibular ramus; MF: Mandibular foramen; N_1 : No. of mandibles; N_2 : No. of findings; PM: Posterior margin of the mandibular ramus; R^2 : Coefficient of determination; SM: Superior margin of the mandibular ramus; TC: Temporal crest (internal oblique ridge) of the mandibular ramus.

Discussions

The measured values in this study concerning the MF topography were obtained by direct and imaging morphometry carried out on 69 mandibles. The following average values were determined: MF–AM distance 14.7 mm on the right and 15.2 mm on the left; MF–PM distance 10 mm on the right and 10.33 mm on the left; MF–IM distance 23.46 mm on the right and 24.13 mm on the left; MF–SM distance 15.63 mm on the right and 15.13 mm on the left; MF–TC distance 10.56 mm on the right and 10.66 mm on the left; vertical diameter of the MF 7.6 mm on the right and 7.93 mm on the left; horizontal diameter of the MF 5.86 mm on the right and 5.83 mm on the left.

According to the results presented in this study, the MF is closer to the posterior margin than to the anterior margin, and closer to the superior margin than to the inferior margin of the mandibular ramus. Therefore, the MF is not placed in the center of the mandibular ramus. Also, our results demonstrate the existence of left/right sides topographic symmetry. The vertical diameter is greater than the horizontal one, so MF has an oval shape, and is not round. These results share some similarities with many studies, but there are also some differences.

No other study that determines the position of the MF through both imaging and direct morphometry has been found in the medical literature databases. As far as we know, this is the first study that describes the topography of the MF through both imaging and direct morphometry. Moreover, this is the first study that combines investigations on the topography of the MF in dentate, partially, and completely edentulous mandibles. The study methodology is complex and offers a greater accuracy to the research results. Furthermore, the measurements were taken by the same person, using the same evaluation technique, which led to the removal of some technical errors that might have

occurred if the measurements were taken by different people.

Most of the studies concerning the topography of the MF analyzed the distance between the MF and the four margins of the mandibular ramus. Other studies, fewer in number, also analyzed the position of the MF compared to the temporal crest, the mandibular angle, the mandibular condyle or the third mandibular molar. Morphometric determinations of the distances between the above-mentioned landmarks and the MF were mostly carried out on dry dentate human mandibles, less so on edentulous mandibles.

Authors such as Kilarkaje *et al.* (2005) [9], Peker *et al.* (2009) [10], Ansari & Ahmed (2015) [11] and Patil *et al.* (2015) [12] studied the topography of the MF through panoramic X-rays and showed that the most frequent positioning of the MF in relation to the sagittal plane was in the posterior part of the middle third of the mandibular ramus, the results being symmetrical on both sides.

Other authors, Kamburoğlu *et al.* (2009) [13] and Ağlarci *et al.* (2015) [14], established the position of the MF through CBCT scans.

The results presented by Ağlarci *et al.* (2015) [14], regarding the distances between the MF and the margins of the mandibular ramus were: 15.29±2.60 mm for MF–AM distance, 11.13±2.44 mm for MF–PM distance, 16.70±3.75 mm for MF–SM distance, 24.75±4.62 mm for MF–IM distance, the results matching those in our study.

However, specialized literature is not cohesive in describing the topography of the MF, which varies among different populations [12, 15, 16], within the same population and even in the same individual on the left and right side, in relation to craniofacial growth, gender, age [12]. Therefore, it is appreciated that the topography of the MF should be determined as precisely as possible

prior to any surgery intervention in the mandible [12]. Due to the large topographic variations of the MF, some authors consider that the evaluation of the MF position by CT scans before any surgical approach to the ramus is necessary [17].

A study conducted by Ennes & Medeiros (2009) [6] on the Brazilian population, which analyzed 91 dry dentate and edentulous mandibles, through photographing and then measuring the digital images, showed that the MF is located 14.9 ± 3 mm from the anterior margin of the mandibular ramus, 12.3 ± 2.2 mm from the posterior margin of the mandibular ramus, 23.5 ± 2.8 mm from the superior margin of the mandibular ramus and 21 ± 4.1 mm from the inferior margin of the mandibular ramus. The results differ from those presented in our study. Also, the authors show that despite the great variation in MF positioning, the most frequent placement was in the middle third of the mandibular ramus, in both anteroposterior and supero-inferior directions [6].

According to the research conducted by Prado *et al.* (2010) [16] on the Brazilian population, analyzing 80 dry dentate mandibles and 79 dry edentulous mandibles, the location of the MF in dentate mandibles is 19.2 ± 3.6 mm to the right and 18.8 ± 3.8 mm to the left of the anterior margin of the mandibular ramus, and in edentulous mandibles, it is 17.5 ± 3.2 mm to the right and 17.4 ± 3.4 mm to the left. In dentate mandibles, the MF is located 14.2 ± 2.4 mm to the right and 13.9 ± 2.6 mm to the left of the posterior margin of the mandibular ramus, while in edentulous mandibles, it is 12.8 ± 2.4 mm to the right and 12.9 ± 2.3 mm to the left. In dentate mandibles, the MF is located 23.6 ± 3.1 mm to the right and 23.1 ± 3.0 mm to the left of the superior margin of the mandibular ramus, while in edentulous mandibles, it is 23.4 ± 3.8 mm to the right and 22.9 ± 3.7 mm to the left. In dentate mandibles, the MF is located 28.3 ± 3.9 mm to the right and 28 ± 3.8 mm to the left of the inferior margin of the mandibular ramus, while in edentulous mandibles, it is 26.4 ± 4.2 mm to the right and 26.4 ± 4.0 mm to the left. All results differed from those we found in our study. The authors showed that there are differences between dentate and edentulous mandibles which are of statistical significance, except for the distance between the MF and the superior margin of the mandibular ramus, and that the position of the MF changes with teeth loss, and this variability can be responsible for the occasional failure of the inferior alveolar nerve anesthesia [16].

Thangavelu *et al.* (2012) [7] conducted a study on 93 dry dentate mandibles and nine edentulous mandibles, showing that the MF was 2.75 mm behind the middle of the anteroposterior plane and 3 mm above the middle of the superoinferior plane. The authors also showed the variability of the MF-AM distance and considered this aspect as not being important enough to cause the failure of the inferior alveolar nerve anesthesia, the failures being completely due to human error and not to anatomical variations. Their results differ from those we found: for dentate mandibles, the average MF-AM distance was 18.9 mm on the right and 18.89 mm on the left, the average MF-PM distance was 14.31 on the right and 14.39 mm on the left, and the average MF-IM distance was 27.62 mm on the right and 27.30 mm on the left,

and in the case of edentulous mandibles, the average MF-AM distance was 17.89 mm on the right and 17.56 mm on the left, the average MF-PM distance was 12.56 mm on the right and 13.33 mm on the left, and the average MF-IM distance was 30.78 mm on the right and 30.78 mm on the left.

Mathur & Joshi (2018) [18] conducted a study on the Indian population, on 100 dry dentate and edentulous adult human mandibles and discovered the following: the average distance between the MF and the AM is 15.72 mm on the right and 16.02 mm on the left, the average distance between the MF and the PM is 11.39 mm on the right and 11.58 mm on the left, the average distance between the MF and the SM is 22.65 mm on the right and 22.94 mm on the left, the average distance between the MF and the IM is 21.33 mm on the right and 21.28 mm on the left. Their results had little in common with our findings.

Another morphometric study of 50 dentate and edentulous adult human mandibles, conducted on the Indian population by Nivedha *et al.* (2019) [19] established the following values for the position of the MF: for dentate mandibles, the average MF-AM distance was 16.07 mm on the right and 16.31 mm on the left, the average MF-PM distance was 11.42 mm on the right and 12.94 mm on the left, the average MF-SM distance was 15.54 mm on the right and 15.39 mm on the left, the average MF-IM distance was 21.06 mm on the right and 20.73 mm on the left, and for edentulous mandibles the average MF-AM distance was 15.54 mm on the right and 15.95 mm on the left, the average MF-PM distance was 13.42 mm on the right and 13.38 mm on the left, the average MF-SM distance was 18.71 mm on the right and 18.10 mm on the left, the average MF-IM distance was 24.85 mm on the right and 24.40 mm on the left. Comparing these results with those of our study, it can be seen that, for dentate mandibles, similar values were obtained for MF-AM and MF-SM distances, while different values were obtained for MF-PM and MF-IM distances (greater than ours for MF-PM distance and smaller than ours for MF-IM distance), and for edentulous mandibles, the results for all the distances analyzed were different (greater than ours).

Other authors, such as Oguz & Bozkir (2002) [15], Shenoy *et al.* (2012) [17], Hoque *et al.* (2013) [20], Gopalakrishna *et al.* (2016) [21], Sultana *et al.* (2016) [22], Khan & Ansari (2016) [23], Shalini *et al.* (2016) [24], Lalitha *et al.* (2016) [25], Rajkumari *et al.* (2017) [26], and Sultana & Sreekanth (2019) [27], analyzed the topography of the MF only on dry edentulous mandibles, and their findings were different from those we are presenting in this study.

As shown in a recent literature review [3], Khan & Ansari (2016) [23] have mentioned that the absence of specific bone landmarks, alongside variations in height and width of the mandibular ramus are causes of failure of the inferior alveolar nerve anesthesia.

According to the same literature review [3], Sultana *et al.* (2016) [22] show that the clinical success rate of the inferior alveolar nerve anesthesia is quite low due to the imprecise location of the MF. Through their investigations, Sultana *et al.* (2016) [22] located the MF

thusly: 17.69 ± 2.70 mm from the anterior margin of the mandibular ramus on the right side and 17.94 ± 2.73 mm on the left side, 11.39 ± 1.93 mm from the posterior margin of the mandibular ramus on the right side and 11.40 ± 2.01 mm on the left side, 22.90 ± 3.57 mm from the superior margin of the mandibular ramus on the right side and 22.39 ± 3.18 mm on the left side, 23.87 ± 4.52 mm from the mandibular angle on the right side and 23.66 ± 4.36 mm on the left side, and 17.9 ± 3.57 mm from the third molar on the right side 17.6 ± 3.77 mm on the left side.

We have found only one study in the specialized literature, which analyzed the distance between the MF and the temporal crest, with the following results: 13.38 mm on the right side and 13.68 mm on the left side [7]. We consider that this anatomic landmark was unjustly neglected. This anatomic landmark can be clinically identified accurately quite easily and that is way we gave it particular importance in our research.

Studies also indicate that precise determination of MF topography is influenced by the accuracy of the technique used [12] and by the study methodology [28].

Other authors showed the effects that age [29, 30] and tooth loss [16, 30] can have on the position of the MF in the sagittal (anteroposterior) plane, effects which can be responsible for the occasional failure of the loco-regional anesthesia of the inferior alveolar nerve.

A thorough knowledge of the described relationships of the MF is clinically relevant also for properly performing the sagittal split of the mandibular ramus, which is the procedure most used to surgically reposition the mandible [31].

Dental therapeutic failure concerning locoregional anesthesia in the oral and maxillofacial region may be due to variations in the passage foramina of the trigeminal branches that innervate the teeth, the gingiva, and the alveolar bone, and due to variations in the mandibular canal topography, but also due to human error [32–35].

✉ Conclusions

This research illustrates the variability of the morphometric parameters of the MF. The results should increase the level of awareness among dentists with respect to MF topography changes with loss of teeth and help dental practitioners in refining the inferior alveolar nerve block techniques.

Conflict of interests

The authors declare that they have no conflict of interests.

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References

- [1] Buch HA. Clinical anatomy of inferior alveolar nerve block anesthesia. *Clin Anat*, 2011, 24(4):515–517. <https://doi.org/10.1002/ca.21136> PMID: 21374723
- [2] Khoury J, Mihailidis S, Ghabriel M, Townsend G. Anatomical relationships within the human pterygomandibular space: relevance to local anesthesia. *Clin Anat*, 2010, 23(8):936–944. <https://doi.org/10.1002/ca.21047> PMID: 20949494
- [3] Gherghiță OR, Nimigean VR, Moraru SA, Poll A, Nimigean V. [The topography of the mandibular foramen – review of the specialised literature]. *Rom J Stomatol*, 2018, 64(1):22–26. <https://doi.org/10.37897/RJS.2018.1.4>
- [4] Boronat-López A, Peñarocha-Diago M. Failure of locoregional anesthesia in dental practice. Review of the literature. *Med Oral Patol Oral Cir Bucal*, 2006, 11(6):E510–E513. PMID: 17072256
- [5] Nimigean V. Anatomie clinică și topografică a capului și gâtului pentru medicina dentară – note de curs. Ed. Cernaprint, București, 2014 (in Romanian).
- [6] Ennes JP, Medeiros RM. [Localization of mandibular foramen and clinical implications]. *Int J Morphol*, 2009, 27(4):1305–1311. <https://doi.org/10.4067/S0717-95022009000400053>
- [7] Thangavelu K, Kannan R, Kumar NS, Rethish E, Sabitha S, Sayeeganes N. Significance of localization of mandibular foramen in an inferior alveolar nerve block. *J Nat Sci Biol Med*, 2012, 3(2):156–160. <https://doi.org/10.4103/0976-9668.101896> PMID: 23225978 PMID: PMC3510910
- [8] Shah K, Shah P, Parmar A. Study of the location of the mandibular foramina in Indian dry mandibles. *Global J Res Anal*, 2013, 2(7):128–130. <https://www.worldwidejournals.com/global-journal-for-research-analysis-GJRA/article/study-of-the-location-of-the-mandibular-foramina-in-indian-dry-mandibles/OTc0/>
- [9] Kilarkaje N, Nayak SR, Narayan P, Prabhu LV. The location of the mandibular foramen maintains bilateral symmetry in mandibles of different age-groups. *Hong Kong Dent J*, 2005, 2(1):35–37. https://www.hkda.org/hkdj/V2/N1/V2N1_P35_OA4.pdf
- [10] Peker I, Gungor K, Semiz M, Tekdemir I. Localization of mental and mandibular foramina on the conventional and digital panoramic images. *Coll Antropol*, 2009, 33(3):857–862. PMID: 19860115
- [11] Ansari AS, Ahmed I. Localization of the mandibular foramen on the panoramic radiographs. *J Ayub Med Coll Abbottabad*, 2015, 27(3):576–579. PMID: 26721011
- [12] Patil K, Gulegdud MV, Bhattacharya PT. Reliability of panoramic radiographs in the localization of mandibular foramen. *J Clin Diagn Res*, 2015, 9(5):ZC35–ZC38. <https://doi.org/10.7860/JCDR/2015/11641.5893> PMID: 26155559 PMID: PMC4484151
- [13] Kamburoğlu K, Kiliç C, Ozen T, Yüksel SP. Measurements of mandibular canal region obtained by cone-beam computed tomography: a cadaveric study. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*, 2009, 107(2):e34–e42. <https://doi.org/10.1016/j.tripleo.2008.10.012> PMID: 19138636
- [14] Ağlarci OS, Güngör E, Altunsoy M, Nur B, Ok E, Çolak M. Three-dimensional analysis of mandibular foramen location: a cone beam computed tomography study. *OMICS J Radiol*, 2015, 4(1):179. <https://doi.org/10.4172/2167-7964.1000179>
- [15] Oguz O, Bozkir MG. Evaluation of location of mandibular and mental foramina in dry, young, adult human male, dentulous mandibles. *West Indian Med J*, 2002, 51(1):14–16. PMID: 12089867
- [16] Prado FB, Groppo FC, Volpato MC, Caria PHF. Morphological changes in the position of the mandibular foramen in dentate and edentate Brazilian subjects. *Clin Anat*, 2010, 23(4):394–398. <https://doi.org/10.1002/ca.20973> PMID: 20235169
- [17] Shenoy V, Vijayalakshmi S, Saraswathi P. Osteometric analysis of the mandibular foramen in dry human mandibles. *J Clin Diagn Res*, 2012, 6(4):557–560. <https://jcd.net/articles/PDF/2137/2%20-%203873.pdf>
- [18] Mathur S, Joshi P. A morphometric analysis of mandibular foramen in dry human mandibles of Indian population in Rajasthan State. *Int J Med Health Res*, 2018, 4(7):159–163. <http://www.medicalsciencejournal.com/archives/2018/vol4/is sue7/4-7-62>
- [19] Nivedha M, Thenmozhi MS, Lakshmanan G. The morphometric study of mandibular foramina in dentate and edentulous human mandibles in Tamil Nadu. *Drug Invent Today*, 2019, 11(8):1864–1867. <https://jprolutions.info/files/final-file-5d57fec2cc62d5.93179797.pdf>
- [20] Hoque MM, Ara S, Begum S, Kamal AM, Momen MA. Study of morphometric analysis of mandibular foramen in Bangladeshi dry adult human mandible. *Bangladesh J Anat*, 2013, 11(2):58–61. <https://doi.org/10.3329/bja.v11i2.20671>
- [21] Gopalakrishna K, Deepalaxmi S, Somashekara SC, Rathna BS. An anatomical study on the position of mandibular foramen in 100 dry mandibles. *Int J Anat Res*, 2016, 4(1):1967–1971. <https://doi.org/10.16965/ijar.2016.122>

- [22] Sultana Q, Shariff MH, Avadhani R. Study of surgical landmarks of mandibular foramen for inferior alveolar nerve block: an osteological study. *Indian J Clin Anat Physiol*, 2016, 3(1): 37–40. <https://www.ijcap.org/article-details/1430>
- [23] Khan IA, Ansari MA. An anatomical study and clinical correlations of mandibular foramen in dry adult human mandibles of north Indian origin. *Ann Int Med Dent Res*, 2016, 2(4): 161–164. <https://doi.org/10.21276/aimdr.2016.2.4.42>
- [24] Shalini R, RaviVarman C, Manoranjitham R, Veeramuthu M. Morphometric study on mandibular foramen and incidence of accessory mandibular foramen in mandibles of south Indian population and its clinical implications in inferior alveolar nerve block. *Anat Cell Biol*, 2016, 49(4):241–248. <https://doi.org/10.5115/acb.2016.49.4.241> PMID: 28127498 PMCID: PMC 5266106
- [25] Lalitha B, Sridevi NS, Rao EKV. Morphometric analysis of mandibular foramen in dry adult human mandibles. *Int J Sci Stud*, 2016, 4(4):20–22. http://www.ijss-sn.com/uploads/2/0/1/5/20153321/volume_4_issue_4.pdf
- [26] Rajkumari K, Nongthombam SS, Chongtham RS, Huidrom SD, Tharani P, Sanjenbam SD. A morphometric study of the mandibular foramen in dry adult human mandibles – a study in RIMS, Imphal. *IOSR J Dent Med Sci*, 2017, 16(12):39–45. <https://www.iosrjournals.org/iosr-jdms/papers/Vol16-issue12/Version-7/G1612073945.pdf>
- [27] Sultana Z, Sreekanth T. A morphometric study of mandibular foramen in dry adult human mandibles of Indian population in Telangana State. *Int J Anat Res*, 2019, 7(4.2):7080–7085. <https://doi.org/10.16965/ijar.2019.308>
- [28] Samanta PP, Kharb P. [Morphometric analysis of mandibular foramen and incidence of accessory mandibular foramina in adult human mandibles of an Indian population]. *Rev Arg Anat Clin*, 2013, 5(2):60–66. <https://doi.org/10.31051/1852.8023.v5.n2.14059>
- [29] Ashkenazi M, Taubman L, Gavish A. Age-associated changes of the mandibular foramen position in anteroposterior dimension and of the mandibular angle in dry human mandibles. *Anat Rec (Hoboken)*, 2011, 294(8):1319–1325. <https://doi.org/10.1002/ar.21429> PMID: 21714109
- [30] Lipski M, Tomaszewska IM, Lipska W, Lis GJ, Tomaszewski KA. The mandible and its foramen: anatomy, anthropology, embryology and resulting clinical implications. *Folia Morphol (Warsz)*, 2013, 72(4):285–292. <https://doi.org/10.5603/fm.2013.0048> PMID: 24402748
- [31] Daw JL Jr, de la Paz MG, Han H, Aitken ME, Patel PK. The mandibular foramen: an anatomic study and its relevance to the sagittal ramus osteotomy. *J Craniofac Surg*, 1999, 10(6): 475–479. PMID: 10726499
- [32] Nimigean V, Nimigean VR, Buțincu L, Sălăvăstru DI, Podoleanu L. Anatomical and clinical considerations regarding the greater palatine foramen. *Rom J Morphol Embryol*, 2013, 54(3 Suppl):779–783. PMID: 24322027
- [33] Gherghiță OR, Nimigean VR, Cismas SC, Nimigean V. Mental foramen topography in dentate subjects – a retrospective study by review of the literature. *Rom J Oral Rehabil*, 2019, 11(2):22–34. <http://www.rjor.ro/mental-foramen-topography-in-dentate-subjects-a-retrospective-study-by-review-of-the-literature/>
- [34] Sîrbu VD, Perlea P, Nimigean VR, Bădiță DG, Șerban A, Nimigean V. Morphological assessment of the mandibular canal trajectory in dentate subjects. *Rom J Morphol Embryol*, 2017, 58(4):1401–1408. PMID: 29556634
- [35] Nimigean V, Sîrbu VD, Nimigean VR, Bădiță DG, Poll A, Moraru SA, Păun DL. Morphological assessment of the mandibular canal trajectory in edentate subjects. *Rom J Morphol Embryol*, 2018, 59(1):235–242. PMID: 29940633

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