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Clinical and anatomical study of foramen locations in jaw bones and adjacent structures

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Abstract

This study aims to find and locate foramens exactly in maxilla and mandible in case of complications during surgeries.

Computer topographic angiography (CTA) images of 120 cases were reviewed. The measurements were performed on coronal, sagittal and axial planes after the 3 dimension volume reconstruction. The distances among foramens, bony landmarks, teeth, and facial artery were all measured with the angles as adjustments.

The incisive foramen (IF) was measured 20.55 ± 2.81 mm to margo inferior of incisor, and 45.27 ± 5.27 degree from the axial midline. The greater palatine foramen located 43.17 ± 2.55 mm from the IF, while 21.08 ± 3.75 degree from the midline in axial plane. The lesser palatine foramina located 44.56 ± 5.74 mm from the IF and 20.05 ± 3.59 degree to the midline. The Mandibular foramen (MBF) was 91.15 ± 1.86 mm horizontally to the margo inferior of incisor. The angle that the MBF-margo inferior of incisor line made with the axial midline was 31.25 ± 2.89 degree. The shortest horizontal distance from the mental foramen (MF) to the facial artery in sagittal plane was 21.90 ± 1.86 mm, while it became 13.00 ± 2.05 mm in coronary section. The horizontal distance from the MF to the margo inferior of incisor in sagittal plane was 22.04 ± 3.22 mm. It turned out to be 25.78 ± 5.23 mm between MF and mid-sagittal line in coronary section. The vertical distance was 25.20 ± 3.06 mm from the upper margin of the second premolar to the MF.

The foramens were clearly seen through CTA. Moreover, linear and angular measurements were presented, which makes it safer and wiser for surgeons to consider the biometric data before operations.

Abbreviations: AB = the distance from incisive foramen (A) to margo inferior of incisor (B), ∠ABM = the angle between the incisive canal-margo inferior of incisor line and axial middle line (Line M), AD = the length of incisive canal from incisive foramen (A) to its opening in nasal cavity (D), B = the margo infeior of incisor, C = the point of the middle line of the palate, CTA = computer topographic angiography, D = the opening in the nasal cavity of incisive canal, ∠DAC = the angle between incisive canal and hard palate, EB = the horizontal distance from mental foramen (E) to margo inferior of incisor (B) in sagittal plane, EF = the shortest horizontal distance from mental foramen (E) to facial artery (F) in sagittal plane, EG = the shortest horizontal distance from mental foramen (E) to 1 point of facial artery (G), ES = the horizontal distance from mental foramen (E) to mid-sagittal line (S), F = facial artery 2, G = facial artery1, GPF (L) = greater palatine foramen, H = the upper margin of the second premolar, HE = the distance from the upper margin of the second premolar (H) to the mental foramen (E), IF (A) = incisive foramen, JB = the horizontal distance from mandibular foramen (J) to margo inferior of incisor (B), ∠JBM = the angle between mandibular foramen-margo inferior of incisor line and the axial midline (Line M), JM = the horizontal distance from mandibular foramen (J) to the axial midline (Line M) in coronary section, ∠KAM = the angle between the incisive foramen-lesser palatine foramen line (KA) and the axial midline (Line M), KA = the horizontal distance from lesser palatine foramina (K) to incisive foramen (A), LA = the horizontal distance from greater palatine foramen (L) to incisive foramen (A), ∠LAM = the angle that the incisive foramen-greater palatine foramen line (LA) made with the axial midline (Line M), Line M = the axial midline, LK = the distance from greater palatine foramen (L) to lesser palatine foramina (K), LPF(K) = lesser palatine foramina, MBF (E) = mandibular foramen, MF(J) = mental foramen, S = mid-sagittal line.

Keywords: anesthesia, CTA, greater palatine foramen, mandibular foramen, mental foramen, oral maxillofacial surgery

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1. Introduction

The foramens in jaw bones, maxilla and mandible, deserve special attentions, through which vital neurovascular bundles are running. There are incisive foramen (IF), greater palatine foramen (GPF), and lesser palatine foramina (LPF) in the maxilla. IF is right behind central incisor tooth, which carries the nasopalatine nerve and the sphenopalatine artery responsible for most serious posterior epistaxis.[1] The GPF commonly locates at either posterior angle of the hard palate. And the LPF, which is neighbor ply behind the greater one, riddles the pyramidal process of the palatine bone. The greater palatine nerve and the lesser palatine nerve pass through the GPF and LPF respectively to innervate palate, mucosa and glands, and tonsil.

Mandibular foramen (MBF) and mental foramen (MF) are located at the mandible. And the opening of MBF is near the ramus of the mandible for the mandibular nerve to descend through. Being the largest of the 3 divisions of the trigeminal nerve, the mandibular nerve gives off branches of the inferior alveolar nerve traveling in the mandibular canal. At the MF where the inferior alveolar nerve exits, it is known as mental nerve. It is well documented that the serious injuries of inferior alveolar nerve in the MF resulted from surgery includes wisdom tooth removal, dental implant replacement, and deep dental anesthesia.[2,3] As it reveals, these foramens in jaw bones are of the great clinical significance. Therefore, clinicians are required to be aware of the potential risks. Otherwise, they might injure the sprawling neurovascular bundles.

However, researches on the positions of the foramens need further study, considering that most of existing literatures are performed on unsexed dry skulls with very few clinical records.[4] Additionally, more accurate and exact measurement should be applicated, so that predictable surgeries could be performed more accurately.

Computed tomography angiography (CTA) has enabled high resolution of intracranial vascular roadmap sketched with contrast media.[5] Generally, this study aims to relocate the foramens in the maxilla and the mandible using CTA. The distance from IF, margo inferior of incisor, facial artery, and midlines were all measured. Helpfully, this study not only updates the knowledge of the foramen locations in the jaw bones, but also provides guidelines for anesthesia and oral maxillofacial surgery.

2. Materials and methods

This study protocol was approved by the Ethics Committee of The First Hospital of Jilin University. Patient records were anonymized and de-identified before the analysis. The 120 CTA images of the jaw bones in the individuals (68 males and 52 females) with ages ranging from 8 to 82 years (mean 46.8 years) were reviewed. After checking body donation documents, it was confirmed that history of diseases or surgical operations were noted in the areas measured. All the CT slices were obtained by the Toshiba 320 row volume CT (0.5 mm between 2 pictures; Toshiba Corporation, Tokyo, Japan) in the First Hospital of Jilin University. The measurements were performed on the coronal, sagittal, and axial planes after 3-dimension reconstruction in computer.

2.1. Imaging measurements procedures

Three dimensional volume reconstructions were performed to rebuild the 3-dimensional structures of the interested region to determine some important structures more precisely, such as IF, GPF, LPF, MBF, and MF. The important anatomic bony structures and facial artery were identified on CTA high-density images as well.

After all the anatomical structures were identified, the sagittal plane of the samples was selected. We measured the distance AB from IF to margo infeior of incisor, the length AD of incisive canal from IF to its opening in the nasal cavity. ∠DAC, the angle between incisive canal and palate, and ∠ABM, the angle between IF-margo infeior of incisor line and axial midline (Line M) were also measured (Fig. 1).

Additionally, the GPF was located by measuring the horizontal distance LA from GPF to IF. KA noted the horizontal distance from LPF to IF, and LK noted the distance from greater palatine foramina to LPF. Moreover, from GPF to LPF was the distance LK. ∠LAM, the angle between the IF-GPF (LA) line and the axial midline (Line M), was also measured. Furthermore, ∠KAM noted the angle between incisive foramina-LPF (KA) and the axial midline (Line M) (Fig. 2).

Then, we measured the horizontal distance JB from MBF to margo infeior of incisor (Fig. 3A), and the horizontal distance JM from MBF to the axial midline (Line M) (Fig. 3B), as well as ∠JBM, the angle between MBF-margo infeior of incisor line and axial midline (Line M) separately (as shown in Fig. 3A).

We further measured the horizontal distance EB from MF to margo infeior of incisor in sagittal plane, the shortest horizontal distance EF from MF to 1 point of facial artery in sagittal plane (Fig. 4A), the horizontal distance ES from MF to mid-sagittal line, and the shortest horizontal distance EG from MF to 1 point of facial artery (Fig. 4B). Additionally, the vertical distance HE from the upper margin of the second premolar to the MF was determined.

2.2. Statistical analysis

All the statistics were entered into SPSS 18.0 (SPSS Inc, Chicago, IL) for analysis. The measurements were presented as mean ±

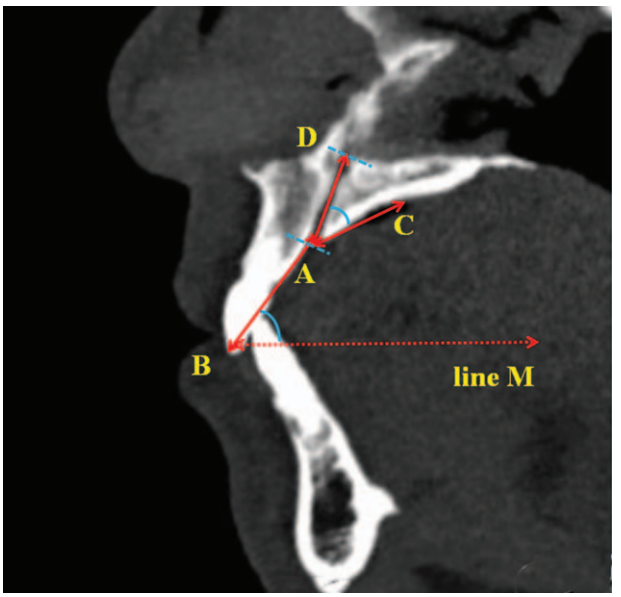

Figure 1. A, Incisive foramen; B, margo infeior of incisor; C, hard palate; D, incisive foramen opening in the nasal cavity. ∠ABM = the angle between incisive foramen-margo infeior of incisor line and the axial midline (Line M), ∠DAC = the angle between incisive canal and palate.

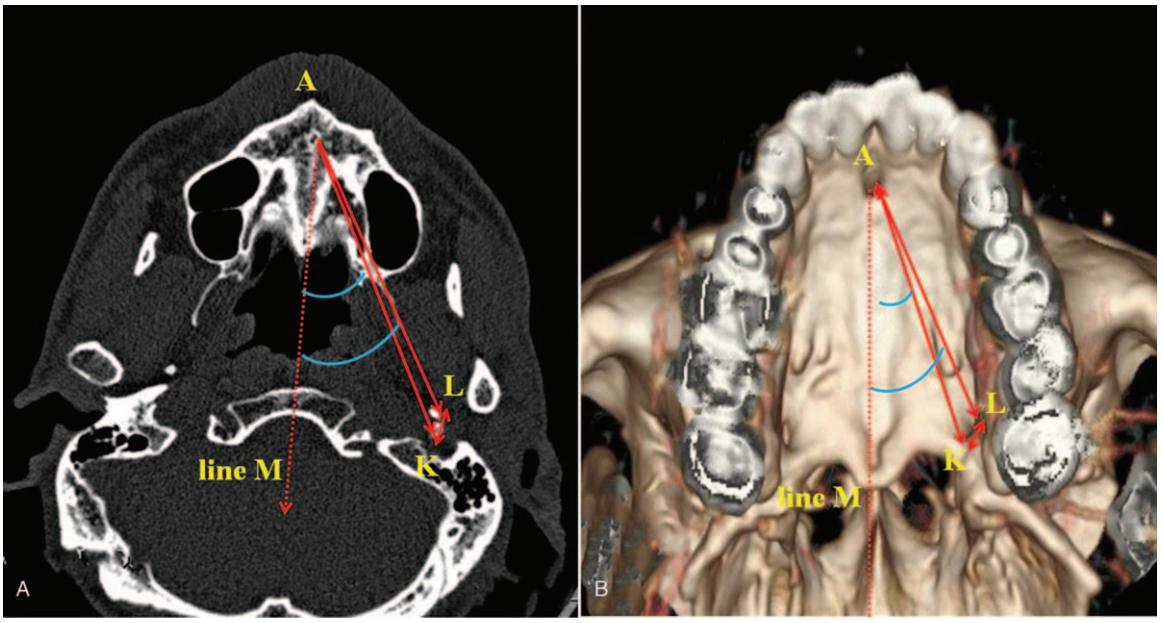

Figure 2. A, Incisive foramen; K, lesser palatine foramina; L, greater palatine foramina. ∠KAM = the angle between the incisive foramen-lesser palatine foramen line (KA) and the axial midline (Line M), ∠LAM = the angle between the incisive foramen-greater palatine foramen line (LA) and the axial midline (Line M).

standard deviation. We had normality tests for all the data. Also, differences between the 2 hemispheres were tested by an independent-sample test. Result is $P < .05$, which noted that there was a statistical significance between 2 hemispheres.

3. Results

The IF (A), the GPF (L) and the LPF (K) in the maxilla as well as the MBF (E) and the MF (J) in the mandible were identified after the 3D volume reconstruction. Furthermore, vessels could also be detected by CTA. Additionally, the relative distances from the foramens to their adjacent anatomical structures were measured, in addition to the angles as another metric. Thereby, the newly figured foramen positions were fixed and exhibited to reach further comprehension and guide the surgery. The detailed procedures and results were as followings:

3.1. Locating of IF, GPF, and LPF

The foramens underneath the maxilla were distinguished in sagittal and axial plane. It showed that the distance AB, between IF (A) and margo infeior of incisor (B), is 20.55 ± 2.81 mm, which can help to locate the IF sagittally (Fig. 1). Additionally, the length AD of incisive canal was 17.78 ± 3.24 mm. The angle ∠DAC between the directions of line DA and line CA was further measured to be 42.92 ± 4.52 degree. And the angle ∠ABM between the directions of line AB and the axial midline (Line M) was 45.27 ± 5.27 degree. Accordingly, the IF was located.

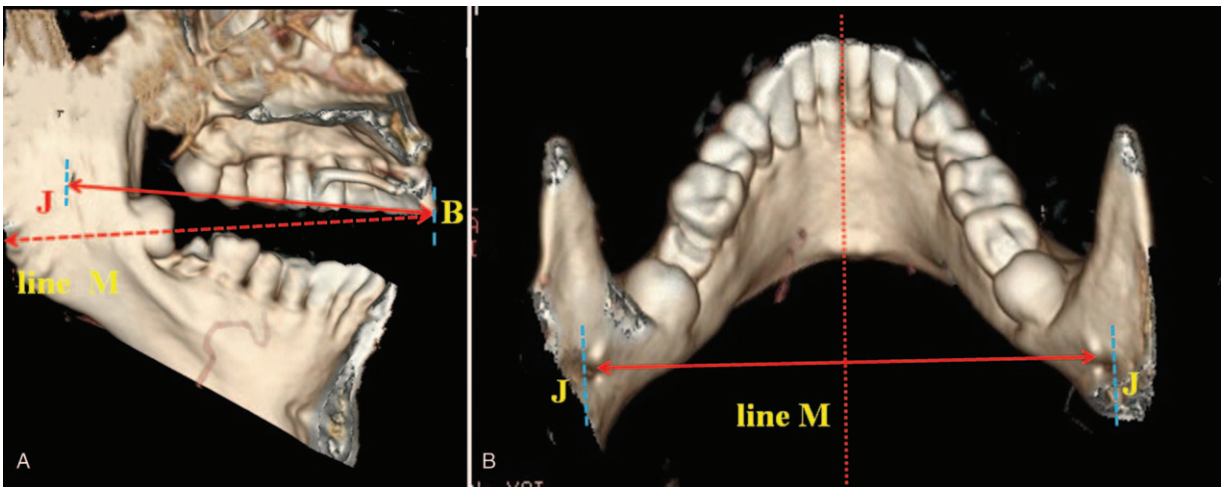

Figure 3. B, Margo inferior of incisor; J, mandibular foramen. ∠JBM = the angle between the mandibular foramen-margo inferior of incisor line and the axial midline (Line M).

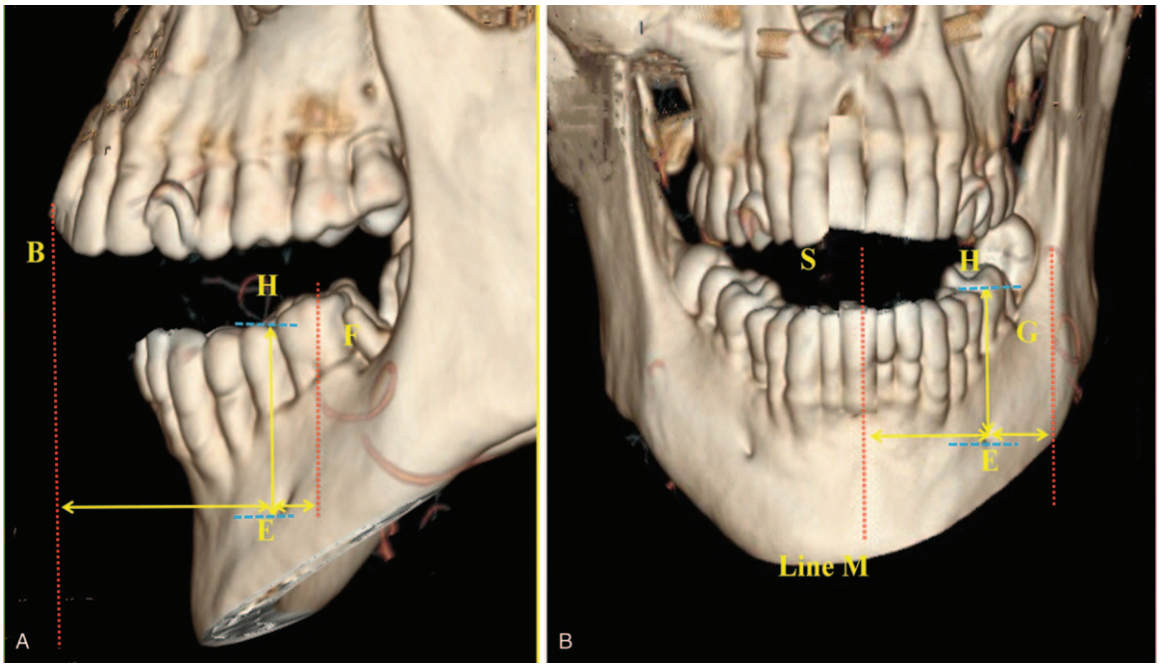

Figure 4. B, Margo inferior of incisor; E, mental foramen; G, facial artery; H, upper margin of the second premolar. (A) EB noted the horizontal distance from mental foramen (E) to margo infeior of incisor (B) in sagittal plane. EF was the shortest horizontal distance from mental foramen (E) to facial artery (F) in sagittal plane. HE was the distance from the upper margin of the second premolar (H) to the mental foramen (E). (B) EG was the shortest horizontal distance from mental foramen (E) to facial artery (G) in coronary plane. ES noted the horizontal distance from mental foramen (E) to mid-sagittal line (S).

In the axial plane, the IF indicated the GPF and the LPF. The distance LA from GPF (L) to IF (A) was 43.17 ± 2.55 mm. Moreover, the angle ∠LAM between the line LA and the axial midline (Line M) was 21.08 ± 3.75 degree. These numbers showed the spot of the GPF explicitly (Fig. 2A and B).

Moreover, the distance LK from GPF (L) to LPF (K) was 5.96 ± 1.08 mm. The horizontal distance KA equaled 44.56 ± 5.74 mm.

Table 1

Length of AB, AD, and angle of ∠DAC, ∠ABM (mm and °).

	AB	AD	∠DAC	∠ABM
Mean	20.55	17.78	42.92	45.27
SD	2.81	3.24	4.52	5.27
Range	17.80–24.90	13.80–21.10	36.00–48.50	36.90–51.30

AB noted the distance from incisive foramen (A) to margo inferior of incisor (B). AD noted the length of incisive canal from incisive foramen (A) to its opening in nasal cavity (D). ∠DAC noted the angle between incisive canal and hard palate. ∠ABM noted the angle between the incisive canal-margo inferior of incisor line and axial middle line (Line M).
SD = standard deviation.

In addition, the angle ∠KAM between the directions of line KA and the axial midline (Line M) was 20.05 ± 3.59 degree after the 120 CT slices' measurements. All the measurements data were shown in Tables 1 and 2. Then, according to normality test for all above data, there was no significant difference between the 2 hemispheres in the above measurements ($P > .05$).

3.2. Locating of the MBF and the MF

It exposed the location of the MBF and the MF in both sagittal plane and coronary plane. First, the horizontal distance JB which was between MBF (J) to margo infeior of incisor (B) was 91.15 ± 1.86 mm (Fig. 3A). Correspondingly, the angle ∠JBM between the directions of line JB and axial midline (Line M) was 31.25 ± 2.89 degree. Furthermore, the horizontal distance JM between MBF (J) and the axial midline (Line M) in coronary section was 44.07 ± 2.31 mm (Fig. 3B). All the measurements data were shown in Table 3.

Out of the feasibility to minimize the injury to friable nerves and vessels, the MF was detected with reference to the facial artery in sagittal plane. It showed that the distance HE from the upper margin of the second premolar (H) to the MF (E) was

Table 2

Length of LA, LK, KA, and angle of ∠LAM, ∠KAM (mm and °).

	LA	LK	KA	∠LAM	∠KAM
Mean	43.17	5.96	44.56	21.08	20.05
SD	2.55	1.08	5.74	3.75	3.59
Range	39.40–54.00	4.50–6.90	42.50–56.50	15.90–26.20	15.10–26.00

LA noted the horizontal distance from greater palatine foramen (L) to incisive foramen (A). LK noted the distance from greater palatine foramen (L) to lesser palatine foramina (K). KA noted the horizontal distance from lesser palatine foramina (K) to incisive foramen (A). ∠LAM noted the angle that the incisive foramen-greater palatine foramen line (LA) made with the axial midline (Line M). ∠KAM noted the angle between the incisive foramen-lesser palatine foramen line (KA) and the axial midline (Line M).
SD = standard deviation.

Table 3

Length of JB, JM, and angle of ∠JBM (mm and °).

	JB	JM	∠JBM
Mean	91.15	44.07	31.25
SD	1.86	2.31	2.89
Range	87.80–94.10	39.90–47.50	26.80–36.00

JB noted the horizontal distance from mandibular foramen (J) to margo inferior of incisor (B). JM noted the horizontal distance from mandibular foramen (J) to the axial midline (Line M) in coronary section. ∠JBM noted the angle between mandibular foramen-margo inferior of incisor line and the axial midline (Line M).
SD = standard deviation.

25.20 ± 3.06 mm. And the horizontal distance EB from the MF (E) to the margo infeior of incisor (B) in sagittal plane was 22.04 ± 3.22 mm. Also, the shortest horizontal distance EF which was between the MF (E) to facial artery (F) in sagittal plane was 21.90 ± 1.86 mm (Fig. 4A).

Additionally, in coronary plane, the horizontal distance ES which was between MF (E) and mid-sagittal line (S) was 25.78 ± 5.23 mm. Moreover, the shortest horizontal distance EG between MF (E) and facial artery (G) was 13.00 ± 2.05 mm (Fig. 4B). All the measurements data were shown in Table 4. According to normality test for above data, there was also no significant difference between the 2 hemispheres in the above measurements ($P > .05$).

4. Discussion

Before surgeries in the mouth and jaw, blocking nerves in the foramens helps clinicians to proceed surgery accurately, such as in tooth implants, jaw correction, tooth correction, and so on, which has been used widely and raised increasingly interests.[6] Unexpected emergency to neurovascular bundles in the foramens remains another concern. Yet, classic textbooks describe the exact foramen locations roughly.[7] Consensus fails to be reached. Additionally, clinical anatomical researches is limited, at the same time, the booming development of detection technology has not been made good use of. Last but not least, comprehensive analysis of the structures is lacked.

This study collected the contemporary population with known sex, age and clinical data to overcome the limits of existing articles. More importantly, it was the first time that those foramens in jaw bones were located relative to margo inferior of incisor, axial midline (Line M), and facial artery. Additionally, the use of CTA clearly showed subtle bony landmarks, foramens, bony canals, and cranial vessels. After identification of reference points, namely IF, margo inferior of incisor and facial artery, the mean linear and angular measurements in 3 planes disclosed the foramen locations. Then the data also facilitated the detection of the neurovascular bundles passing through. Finally, possible regions to track foramens during surgery were set up.

4.1. The location of IF, GPF, LPF in maxillary

The IF and margo inferior of incisor were regarded as reference points. First, at margo inferior of incisor (B) 45.27 ± 5.27 degree (∠ABM) above the axial midline (Line M), the IF (A) was found showing the absolute distance AB 20.55 ± 2.81 mm from margo inferior of incisor. Further, the 17.78 ± 3.24 mm incisive canal, 42.92 ± 4.52 degree (∠DAC) above the palate, connected the nasal and the oral cavity.

Then the GPF and the LPF were determined. The GPF (L) opened 43.17 ± 2.55 mm from the IF (A), while 21.08 ± 3.75 degree (∠LAM) distal to the midline (Line M). Also, the LPF (K) behind the GPF was simultaneously located 44.56 ± 5.74 mm away from the IF (A). Also, it was 20.05 ± 3.59 degree (∠KAM) to the midline (Line M) in terms of the angle. To be specific, the distance between the greater and lesser foramens was 5.96 ± 1.08 mm. Thus, a possible region for locating foramens was formed, so that not only were the foramens determined but the contained neurovascular networks would be found.

This possible region related to the foramens in maxilla required cautions and patience from surgeons. For example, 1 common intraoral approach to access the maxillary nerve is through greater palatine canal, in which a needle is inserted through the GPF.[8] If an anesthetic needle happened to surpass the distance 43.17 ± 2.55 mm or the angle 21.08 ± 3.75 degree, large area of soft tissue would be unnecessarily removed to track the foramens in prolonged operation time.

Additionally, the possible area of the foramens was also investigated in previous studies. For instance, the mean distance from GPF to the incisive fosse was 37.3 mm in the study of Saralaya and Nayak.[9] Moreover, it was the distance from anterior wall of the GPF to the posterior border of the IF being 36.52 ± 3.34 mm in Chrcanovic and Custódio.[10] Furthermore, age, race, and methodology might explain the little differences among the studies.

However, the nasopalatine nerve through the IF could be cut off if necessary.[11] Removal of some soft tissues might cause sensory loss of anterior palate but resolved the problems. Because the innervations of this area were so dense that nasopalatine nerve might contribute little. Additionally, insufficient bone volume resulting from age, tooth extraction, and orthodontic treatment add difficulties and challenges for implants placement, especially the incisive canal in relation to maxillary central incisor plants.

Table 4

Length of EB, EF, EG, ES, and HE (mm).

	EB	EF	EG	ES	HE
Mean	22.04	21.90	13.00	25.78	25.20
SD	3.22	1.86	2.05	5.23	3.06
Range	19.60–28.00	19.90–22.80	12.20–14.10	22.50–29.20	22.50–27.60

EB noted the horizontal distance from mental foramen (E) to margo inferior of incisor (B) in sagittal plane. EF noted the shortest horizontal distance from mental foramen (E) to facial artery (F) in sagittal plane. EG noted the shortest horizontal distance from mental foramen (E) to 1 point of facial artery (G). ES noted the horizontal distance from mental foramen (E) to mid-sagittal line (S). HE noted the distance from the upper margin of the second premolar (H) to the mental foramen (E).
SD = standard deviation.

4.2. The location of MBF and MF in mandible

Surgeons can locate margo inferior of incisor and axial midline easily. The MBF (J) in the mandible is 91.15 ± 1.86 mm horizontally to the margo infeior of incisor (B). And it was 31.25 ± 2.89 degree in terms of the angle ($\angle$JBM) line JB made with the axial midline (Line M). Additionally, the location turned out to be more specific when taking horizontal distance JM of coronary plane into consideration, which was 44.07 ± 2.31 mm between the MBF (J) and the axial midline (Line M).

Furthermore, the facial artery was also easily identified through CTA. The shortest horizontal distance EF from the MF (E) to the facial artery (F) in sagittal plane was 21.90 ± 1.86 mm. Therefore, the exact shortest distance from the MF to the facial artery on the actual mandible could be ascertained, with reference to the shortest horizontal distance EG being 13.00 ± 2.05 mm in coronary section.

Similarly, the exact shortest distance from the MF to the margo inferior of incisor's projection point in axial plane could be calculated out. First, the horizontal distance EB from the MF (E) to the margo infeior of incisor (B) in sagittal plane was 22.04 ± 3.22 mm. And it showed the horizontal distance ES between MF (E) and mid-sagittal line (S) was 25.78 ± 5.23 mm in coronary section. Thereby the accurate shortest distance on axial plane is clear. The line HE was 25.20 ± 3.06 mm which shows the vertical distance from the upper margin of the second premolar (H) to the MF (E).

Accurate location of foramens in the mandible improves the success rate for nerve block.[12] The inferior alveolar nerve block anesthesia procedure could be more effective through MBF with reference to 91.15 ± 1.86 mm horizontally to the margo infeior of incisor (B) and 44.07 ± 2.31 mm to the mid-axial line. Additionally, anesthetists should also perform the operations with the angle ($\angle$JBM) 31.25 ± 2.89 degree, because chin skin necrosis might occur due to inferior alveolar artery spasm by ectopically delivered anesthesia.[13] Once the MBF was set, following surgeries proceeded by utilizing the spot as indication.

As we all know, the mental nerve block through MF was carried out by multiple discipline clinicians.[14] Reports of lower lip sensory disturbance were also common as a result of damage to the anterior loop of mental nerve.[15] However, clinicians could avoid injuring mental neurovascular bundles if they were familiar with the presented data. It was innovative to measure facial artery as fourth reference point using CTA. Considering 21.90 ± 1.86 mm to the facial artery as extra correction, the MF and the anterior loop had more accurate possible region than conventionally according to the margo inferior of incisor, the midline and the second premolar. Consequently, post-surgical complications were reduced.

Above all, this study exhibited a more accurate method to locate the foramens in maxilla and mandible. But, there were several limits. For example, his study collected Chinese population only. Moreover, though this research was conducted with clear clinical records, larger quantities of samples were to be welcomed.

5. Conclusion

The foramens in the jaw bones were clearly identified with CT and CTA. Morphological parameters among the foramens, bony landmarks, teeth and facial artery, linear and angular measurements, were measured with feasible locating methods. Dentists and oral maxillary surgeons should value and consider the biometrical data presented by this study. Therefore, postoperative complications and iatrogenic injuries would be reduced. Moreover, surgery will be predicted and planned accurately. At the same time, the success rate of surgery will also be improved.

However, the locations and relationship of anatomies in maxillary and mandible could vary from people with such as age, sex, figure, race, development, growth, and so on. Our investigation and data only provide a general reference for surgeons who need concrete analysis of concrete problems. Additionally, as for us, more study need to be done to reveal the regularities of the locations and relationship of anatomies in maxillary and mandible with different people.

Author contributions

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Software: Wu Bo.
Supervision: Jiaxin Ren.
Validation: Jiaxin Ren.
Writing – original draft: Weihang Li.
Writing – review and editing: Weihang Li.

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