Imaging findings of mandibular neurovascular structures using computed tomography

（CT を用いた下顎骨神経脈管系構造の画像所見）

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Abstract

Neurovascular structures exist in the mandible including the mandibular canals and the nutrient canals. The mandibular second molar apices have been reported to be the closest to the mandibular canal and the nutrient canals are most often seen in the anterior region of the mandible. Accurate determinations of the location of the mandibular canal and the nutrient canals prior to dental procedures are crucial to avoid injury. The purposes of this study were 1) To evaluate age and gender-related changes using CBCT images, between the roots of the second molars, mandibular cortex and the mandibular canal. 2) To assess the nutrient canals using MDCT images, including canal prevalence, location, number, size, shape, and the CT values of nutrient foramina.

1) 155 patients were retrospectively analyzed. The patients were subcategorized by gender and age (Group I: <21 years; Group II: 21-40 years; Group III: >40 years). Distance between the mandibular canal and the second molar distal root apex as well as the three mandibular cortical regions was measured on the cross sectional images. 2) 194 patients were retrospectively analyzed.

The results are as follows; 1) In males, the distance between second molar root apex and the mandibular canal was significantly shorter in group I (mean 2.40mm) than group III (mean 4.01mm) (*P*<0.01). In females, the distance between second molar root apex and the mandibular canal was significantly shorter in group I (mean 1.40mm) than group II (mean 2.58mm) and group III (mean 3.36mm) ($P<0.01$).

2) The nutrient canals were seen in 94.3% in the mandible. Nutrient canals were most seen in the anterior region of the mandible. By location, nutrient canals were most commonly seen between the central and lateral incisors. The size of the nutrient foramen varied from 0.4 to 2.0 mm, and the shape was most commonly ovoid. The mean CT value of nutrient foramina was 420 HU±227.

In conclusion, this study has revealed that age, gender and region have an influence on the location of the mandibular canal in the second molar area and 94% were seen mandibular nutrient canal in the mandible. By preoperative knowledge of these findings may useful to plan the treatment and to prevent complications of mandibular surgery.

Introduction

Neurovascular structures exist in the mandible including the mandibular canals and the nutrient canals[1]. The mandibular canal runs through the ramus of the mandible body to the mental foramen[2] giving the branches to the premolar and molar regions[3]. The mandibular canal contains inferior neurovascular bundles which are the inferior alveolar nerve (IAN), artery and vein and supplies the mandibular molar and premolar teeth and adjacent parts of the gingiva[2]. The IAN diverges into the mental nerve and the incisive branch near the premolar region[4-8]. Nutrient canals are derived from the incisive branch of the inferior neurovascular bundles[5-8] which supplies teeth and gingival tissue in the anterior region of the mandible[8] and are visible in about 5% to 40% of all patients on periapical radiographs[9]. Nutrient canals carry neurovascular bundles and appear as radiolucent lines of fairly uniform width on periapical radiographs[9,10]. They are most often seen on mandibular periapical radiographs running vertically from inferior dental canal directly to the apex of a tooth or into the interdental space between mandibular incisors[11].

The reason we care about the mandibular canals and the nutrient canals are because these canals are sometime damaged during various dental intervention such as dental implant treatment, tooth extraction and root canal treatment[12-16]. The injury may result in neuropathic pain, anesthesia or severe hemorrhage[12-17]. The mandibular second molar apices have been reported to be the closest to the mandibular canal compared to the premolars and the first molar[17] and the nutrient canals are most often seen in the anterior region of the mandible compared with premolar and molar regions of the mandible[9]. Dental intervention involving these two regions may have the high risk to have the mandibular canal and the nutrient canals injury. Accurate determinations of the location of the mandibular canals in the second molar region and the nutrient canals in the anterior region of the mandible prior to dental procedures are crucial to avoid injury. Most of the information regarding the mandibular canals and the nutrient canals are usually obtained from conventional periapical or panoramic radiographs. The limitations of 2D radiographs include the lack of buccal-lingual information, interference by the buccal plate, and the inherent magnification and distortion[18]. The advent of 3D imaging such as multi detector row computed tomography (MDCT) and cone beam computed tomography (CBCT) has been crucial in understanding the head and neck structures[18,19]. However, few reports evaluated the mandibular canal in the second molar region and the nutrient canals in the mandible using CT images. There were two purposes in this study. 1) To evaluate age and gender-related changes using CBCT images, between the roots of the second molars, mandibular cortex and the mandibular canal. 2) To assess the nutrient canals using MDCT images, including canal prevalence, location, number, size, shape, and the CT values of nutrient foramina.

Material and Methods

The first study was approved by the Institutional Review Board of Boston University Henry M Goldman School of Dental Medicine (H-33424). The second study was approved by the Institutional Review Board of the Nihon University School of Dentistry at Matsudo (EC12-009).

1) All images were obtained from the radiology database at Boston University Henry M Goldman School of Dental Medicine. All patients signed an informed consent agreement for the CBCT examination. Images were acquired using i-CAT (Imaging Sciences International, Hatfield, PA) at 120 kVp and 4-7 mA with 14-bit gray scale resolution and voxel size of 0.125- 0.3 millimeters. Measurements were made using the i-CAT Vision software and 155 patients' CBCT scans who underwent CBCT from April 2009 to September 2014 were enrolled (68 males, 87 females, mean age 32.3 years; age range, 12-65 years) were randomly selected. The patients were subcategorized by age (Group I: <21 years, mean age 16.9 years, n=51; Group II: 21-40 years, mean age, 29.7 years, n=53; Group III: >40 years, mean age 50.3 years, n=51) and gender. The patients were consisted from multiracial ethnic populations including Caucasoid, Asian, Negroid and Spanish. Inclusion criterion was existing second molar. Exclusion criteria were missing second molar, the second molar root apex was not formed, previous history of

trauma, tumors, cysts and periapical lesions presenting in the mandibular posterior region and patients undergoing orthodontic treatment. All images were evaluated retrospectively by two calibrated examiners and measurements were obtained independently. Distance between the mandibular canal and the second molar distal root apex as well as the three mandibular cortical regions (inferior cortex, buccal cortex and lingual cortex) was measured on cross sectional images as follows (Fig. 1): ①the distal root apex of the mandibular second molar (A) to superior cortical bone of the mandibular canal (MC): A-MC, ② the inferior cortical border of the mandible to the inferior cortex to the MC: I-MC), ③ the lingual cortical border of the mandible to the MC: L-MC, and ④ the buccal cortical border of the mandible to the MC: B-MC. The distance from buccal cortex and lingual cortex to the mandibular canal was measured parallel to the occlusal plane. The distance from the second molar distal root apex to the mandibular canal and from the inferior cortex to the mandibular canal was measured vertical to the occlusal plane. The root apex which was below the mandibular canal recorded as minus. All of the measurements were done on the 3D rendering software Invivo 5 (Anatomage, San Jose, CA) on a Dell UltraSharp 2408WFP 24-inch LCD monitor at a pixel resolution of 1920 X 1200. After interval of two weeks, the distances of four locations in 12 patients were re-measured for data reliability. Paired t-tests were used to evaluate the reliability of the measurements.

Statistical analysis

The data were recorded in Microsoft® Excel® and analyzed using the statistical software added in to the Microsoft® Excel®. Mann-Whitney's U test and Steel-Dwass test was used to compare sex differences and age differences. *P* values less than .05 were considered statistically significant.

2) Of the 552 patients who underwent CT imaging for the evaluation of maxilla, mandible, and maxillary sinus diseases as outpatients at Department of Radiology in Nihon University Dental Hospital at Matsudo (Chiba, Japan), between August 2011 and October 2011, the mandibular CT images of 194 consecutive patients (93 males and 101 females; mean age 47.5 years; age range, 10–79 years) were analyzed retrospectively. All patients were Japanese and signed an informed consent agreement for the CT examination. Exclusion criteria were history of radiotherapy, severe periodontal disease, systemic disease (eg, hematological disorders and diabetes mellitus) with presentation in the mandible, tumor, and cyst with presentation in the mandible; mandible unobservable on CT images; and metal artifacts precluding visualization of the mandible. The CT examinations were performed with a multi detector row CT scanner (Aquilion 64; Toshiba medical, Tochigi, Japan). For the evaluation of maxilla, mandible,

and maxillary sinus, all patients were examined craniofacial area using radiographic protocol for maxilla, mandible, and maxillary sinus examination at our hospital as follows: tube voltage, 120 kV; tube current, 100 mA; field of view, 180 mm × 180 mm; helical pitch, 41; rotation time, 1.0 second; mean effective dose, 1.6 mSv; mean CTDIvol value, 37.3 mGy; mean DLP value, 520.3 mGy cm, using a contiguous high-resolution algorithm for osseous structures (window level 500, window wide 2800). The protocol consisted of axial scanning (0.50 mm) with production of axial multiplanar reformation (3.00 mm). All measurement data were obtained using the Ziostation v1.1x measurement system (Qi Imaging, Tokyo, Japan). Initially, the nutrient canals which were deriving from the incisive branch of the inferior neurovascular bundle and running through lingual cortical bone of the mandible to the alveolar process were searched on sagittal CT images (Fig. 2). These canals were observed on the consecutive axial CT images of 0.5 and 3 mm slice thickness on the monitor display (Fig. 3 a and b). Parameters including canal prevalence, location, number, size (length and width), shape, and the CT value of nutrient foramina were measured. The length was parallel to the mesio-distal direction and the width was parallel to the bucco-lingual direction. The size of nutrient foramen was assessed near the alveolar process on axial CT images of 0.5 mm slice thickness. The other parameters were assessed on axial CT images of 0.5 and

3 mm slice thickness. The shape of nutrient foramen was classified as either round or ovoid (being defined as having a ratio of length/width equal to 1 and smaller/larger than 1, respectively). To assess the CT value of nutrient foramina, region of interest (ROI) were manually drawn in the nutrient foramina. CT values were measured 3 times in these ROIs to enable calculation of the mean CT value. All images were retrospectively evaluated by 2 oral and maxillofacial radiologists who have over 10 years' experience. They observed the axial CT images of 0.5 and 3 mm slice thickness on the monitor independently. After the interval of 2 weeks, the diameter of the nutrient canals and the CT value of nutrient foramina were evaluated with 30 randomly selected patients to statistically evaluate intra observer reliability.

Statistical analysis

The significance assessment of the difference between gender-related differences in the mean number of nutrient canals was statistically evaluated using the Steel-Dwass test. The significance assessment of the gender difference in the mean CT value of nutrient foramen was evaluated by using the Mann- Whitney U test. *P* values less than .05 were considered statistically significant. The paired t tests were used to evaluate the data reliability. Statistical tests were performed using SPSS software version 20 for windows (SPSS, Chicago, IL).

Results

1) Mandibular canals

Data reliability

There was no indication of systemic intra observer errors in the linear measurements between first and second determinations, based on paired t-test.

Age related and gender differences **(**the right and the left sides were combined, Table 1)

In males, A-MC distance was significantly shorter in group I (n=26) (range −2.40 to 8.99 mm mean 2.40mm, SD 2.69) than in group III (n=21) (range −1.16 to 8.36 mm, mean 4.01mm, SD 2.27) (P<0.01). In females, A-MC distance was significantly shorter in group I (n=25) (range −1.84 to 6.28mm, mean 1.40mm, SD 1.69) than in group II (n=32) (range −1.74 to 7.89mm, mean 2.58mm, SD 2.21) and in group III (n=30) (range −2.86 to 11.17mm, mean 3.36mm, SD 2.97) (group I vs group II; P<0.05, group I vs group III; P<0.01).

Differences related to the side of the mandible (Table 2)

In males (n=68), B-MC distance was significantly shorter on the right side (range 2.87 to 8.68mm, mean 4.94 mm, SD 1.57) compared to the left side (range 1.00 to 8.68mm, mean 5.69mm, SD 1.63) (P<0.01). Similarly, in females (n=87), B-MC distance was significantly shorter on the right (range 3.35 to 9.84mm, mean 5.91mm, SD 1.59) than the left side (range 2.34 to 10.23mm, mean 6.06mm, SD 1.36) ($P<0.01$).

Gender Differences related to the side of the mandible (Table 3)

In both sides of the mandible, A-MC distance was significantly shorter in females (n=87) compared to the males (n=68). The average A-MC distance on the right side in females was 2.62 mm (range −1.84 to 11.17mm, SD 2.64) compared to 3.16 mm (range −2.40 to 8.36mm, SD 2.55) in males ($P<0.01$). Similarly the average A-MC distance on the left side was 2.41mm (range −2.86 to 8.77mm, SD 2.36) in females compared to 3.02 mm (range −1.33 to 10.25mm, SD 2.66) in males ($P<0.05$). On the left side, L-MC distance was significantly shorter in males (range 0.39 to 6.95mm mean 2.17mm, SD 1.28) than in females (range 1.08 to 7.16mm, mean 2.74mm, SD 1.19) ($P<0.01$).

Gender differences related to the A-MC distance (the right and the left sides were combined, Table 4)

A-MC distance was significantly shorter in females (n=87) (range −2.86 to 11.17mm, mean 2.51mm, SD 2.51) than in males (n=68) (range −2.40 to 10.25mm, mean 3.21mm, SD 2.61) ($P<0.01$).

2) Nutrient canals

Data reliability

There was no indication of systemic intra observer errors in the measurements between first and second determinations, based on paired t-test.

Prevalence

Of 194 cases, 183 cases (94.3%) were found nutrient canals in the mandible. Of 194 cases, 180 cases (92.7%) were found nutrient canals in the anterior region of the mandible, 83 cases (42%) were found in the premolar region, and 3 cases (1%) were found in the molar region.

Location

The most common sites for mandibular nutrient canals were between the central and lateral incisors: canals between the right central and lateral incisors and between the left central and lateral incisors were found in 89% and 87% of cases, respectively. Nutrient canals were found in other locations in 0% to 26% of patients (Fig. 4).

Gender

The mean number of canals (total and by region) was analyzed for gender specific differences (Fig. 5). Male: total, the anterior region, the premolar region, and the molar region were 2.88, 2.03, 0.83, and 0.01, respectively. Female: total, the anterior region, the premolar region, and the molar region were 2.6, 2.06, 0.48, and 0.02, respectively. There were no significant gender-related differences in the mean number of nutrient canals in the mandible (total), nor in the anterior or molar regions. In contrast, the mean number of nutrient canals in the premolar region (0.83 for male patients and 0.48 for female patients) was significantly different ($P<0.05$). Nutrient canals were seen significantly more often in the anterior region than in the premolar or the molar regions in both male and female patients (Fig. 5).

Size, shape, and CT value of the nutrient foramina between the central and lateral incisors

The length of the nutrient foramina between the right central and lateral incisors varied from 0.4 to 1.8 mm (mean ± SD: 0.9 ± 0.3 mm) (Fig. 6), whereas the width varied from 0.5 to 1.8 mm (mean ± SD: 0.9 ± 0.3 mm) (Fig. 7). On the left side, the length of the nutrient foramina between the left central and lateral incisors varied from 0.4 to 2.0 mm (mean ± SD: 1.0 ± 0.3 mm) (Fig. 8), whereas the width was in the range of 0.4 to 1.8 mm (mean ± SD: 1.0 ± 0.3) (Fig. 9). There were no age-related differences in foramen size. In 35 of 191 cases (18.3%), foramina between the right central and lateral incisors were round, whereas they were ovoid in the remaining 156 cases (81.7%). Similarly, in 33 of 178 cases (18.5%), foramina of canals between the left central and lateral incisors were round, whereas in the remaining 145 cases (81.5%), they were ovoid. The mean CT values (mean ± SD) for nutrient foramina between (1) the right central and lateral incisors and (2) the left central and lateral incisors were 411± 15 HU and 429 ± 207 HU, respectively. In male patients, these values were 404±231 HU and 419±215 HU, respectively, and in female patients, they were 418±199HU and 439±199 HU, respectively. There was no significant difference between these values in male and female patients (P >0.05).

Patient age

The mean number of nutrient canals in the mandible (total) and in the anterior, premolar, and molar regions of the mandible in each decade of life (second decade to eighth decade) are shown in Figure 10. The mean numbers of nutrient canals in total and in the anterior and the molar regions of the mandible were slightly decreased with age. However, the mean number of nutrient canals in the premolar region was slightly increased with age.

Discussion

1) Mandibular canals

Our results indicate the A-MC distance increases with age in both males and females in the second molar region. Kovisto et al[17] studied that root apices in younger patients (<18 years) were generally closer to the mandibular canal than older patients. According to the prior study, the distance between root apices and the mandibular canal increase with eruption of mandibular teeth[20]. Our results may suggest the possibility of increased bone growth after tooth eruption and/or inferior migration of the mandibular canal with age in both genders. Age and sex differences appear to affect the proximity to the mandibular canal to root apices as well as buccal cortex, however the course of the canal traverses through the mandible might vary individually.

Our results revealed A-MC distance was significantly shorter in females than in males. This trend is similar to prior studies[20-23]. Denio et al[21] used sectioning on 22 human dried mandibles to examine the relationship of the mandibular canal to root apices, and found the mandibular second premolar and the second molar had the closest distances to the mandibular canal. Sato et al[22] used panoramic radiographs to measure the distance from root apices to the superior border of the mandibular canal, and found the first and second molar roots were slightly closer to the mandibular canal in females than in males. Overall, the average distance from the mesial root of the second molar to the superior border of the mandibular canal was 0.79±0.44 mm, and that from the distal root was 0.70±0.45 mm. Even though their findings were not statistically significant, a trend can be noticed that the distance from the apex of second molars to the mandibular canal is shorter in females compared to males. Bürklein et al[23] analyzed CBCT images in German population. They measured distance between mandibular second molar distal root apex to the superior border of the mandibular canal. There was a tendency that the distance was shorter in females than males although it was not statistically significant. Our results indicate that differences between female and male may be attributed to the fact that men generally have a larger body size and consecutively show greater distances between the mandibular canal and the root apices[22]. Clinically this indicates that the potential risk of iatrogenic nerve damage may be more common in females[22].

The A-MC distance in our study was greater than the prior study[22]. Our study was performed using CBCT, and not panoramic radiographs which were used in prior study[22]. Therefore, more accurate measurement could be obtained on CBCT images[18]. This may be due to the fact that the lingual mandibular canal is projected higher by the negative angulation of the X-ray tube in a panoramic image. Comparing with the prior studies using CBCT, the A-MC distance was longer than Kovisto et al[17] ‘study though longer than Bürklein et al's study[23]. This may be the result of the different number of the subjects[17] and difference of the country where the study had done[23].

When comparing males with females to the side of the mandible, the left mandibular canal takes more lingual course in males than females and both sides of the mandibular canals run closer to the apex. It was seen in Oliveira Júnior et al's study[20] that there was a tendency that the mandibular canal ran more lingual on the right than the left, although it was not statistically significant. Although, there were few reports that compared the proximity of the mandibular canal to the apex in each side of the mandible. Our results suggest that the canal runs higher in female compared to male therefore the L-MC distance is longer because of the thickness of the lingual cortical bone. Our results revealed that the mandibular canal possibly takes more buccal route in the right mandible than the left in both males and females. A similar trend was observed by de Oliveira Júnior et al[20], where the mandibular canal appears more buccal on the right than the left in both genders. It is also possible the mandible may be narrower on the right side compared to the left as there was no statistically significant difference between the L-MC distances on either side among each group in our study. Further studies will be needed to investigate whether there is asymmetry between the ridges on either side of the mandible.

2) Nutrient canals

Our analysis of CT images revealed that the nutrient canals were running into the lingual cortical bone which ends at near the alveolar process on axial CT images. Clinically, dental implant surgery in the edentulous anterior mandible is considered a routine and relatively safe surgical procedure, but it is not without potential morbidity[25-28]. Complications include hemorrhage from incisive canal[12] and sensory disturbance of incisive canal region[5-7]. The cause was considered trauma to the incisive canal[29]. These complications[25-28] are not related to injury of the nutrient canals. However, the nutrient canals carry neurovascular bundles[5-7]. Morbidity may occur in case the nutrient canals injured.

Prevalence and location

In our study, 93% of the nutrient canals were seen mostly in the anterior region of the mandible. By location, nutrient canals were particularly seen between the central and lateral incisors in the mandible. Patel et al[11] reported that nutrient canals are seen in the anterior region of the mandible 42.5% on average, Kishi et al[10] reported a prevalence of 1% to 65% in the anterior region, and Britt[25] reported nutrient canals were observed in 14% of studied cadavers. These studies evaluated periapical radiographs, but we observed axial CT images of 0.5 and 3mm slice thickness. Our results demonstrated that prevalence of the nutrient canals on axial CT images were higher than that of on periapical radiographs. We considered these differences were due to difference of modality. MDCT use volume scan and detect mandible three dimensionally so the accuracy improves compared with periapical radiographs. Britt[30] reported that nutrient canals are most often seen in the anterior region of the mandible. The mandibular nutrient canals were not observed in 6% of the patients. In such cases, the nutrient canals running up to the lingual cortical bone, but stopped in the middle of the cortical bone.

In our study, prevalence of the nutrient canals in the anterior region is higher than that of other two regions. We think that these canals serve to deliver nutrition to teeth in the anterior region because these teeth are at some distance from the mandibular canal and thus require alternative supply routes.

Our study revealed that nutrient canals were particularly seen between the central and lateral incisors. McCall and Wald[31] reported that nutrient canals are particularly seen between the central and lateral incisors in the mandible on periapical radiographs. We believe that this high prevalence of canals between the central and lateral incisors reflects the fact that these locations are at the terminal ends of the nutrient canals.

Age dependence of canal distribution

Our study revealed that the mean number of nutrient canals slightly decreased in the anterior region of the mandible and in total, whereas the mean number of nutrient canals in the premolar region was slightly increased with age. White and Pharoah[9] stated that nutrient canals are often seen in older person. We believe that, because of the role of nutrient canals in supplying nutrients to the anterior region, they are necessary at all stages of life and thus do not significantly increase or decrease with age.

Gender dependence of canal distribution

Our results show that no significant gender difference in the mean number of nutrient canals in the mandible, in the anterior region of the mandible, and in the molar region of the mandible. White and Pharoah[9] also stated that nutrient canals are more frequent in males than in females. However, there was a significant difference between males and females in the mean number of nutrient canals in the premolar region. This may be a result of gender difference of divergent point at which inferior alveolar canal diverges into the incisive canal and the mental nerve near the premolar region.

Size, shape, and CT Values of nutrient foramina

In our study, the length of the nutrient foramen was varying from 0.4 to 1.8 mm, and the width was varying from 0.5 to 1.8 mm. Regarding aperture of the nutrient foramen, 82% of the formania were ovoid in shape, with only 18% being round. Shimizu[32] reported that diameter of nutrient foramen between the central and lateral incisors vary from <0.3 to >1.2 mm and also reported that 0.5 to 0.7mm is the most frequent diameter in dry human mandible. Shimizu[32] also reported that nutrient foramen is most commonly round in shape. We believe that the nutrient foramen diameter does not change with age because of ongoing necessity of these canals in supplying nutrition to the anterior region of the mandible. Regarding the CT value, nutrient foramina contain neurovascular bundles that being soft tissue should have CT values of 20 to 40 HU[33]. However, our results revealed that the mean CT value of the nutrient foramina between the central and lateral incisors was 420 HU. We believe that the CT values of the nutrient foramina were affected by partial volume effect.

Conclusion

The present study has revealed that age, gender and region have an influence on the location of the mandibular canal in the second molar area and 94% were seen mandibular nutrient canals in the mandible. Dental practitioners need to know accurate location of the mandibular canals and the nutrient canals prior to dental procedures such as dental implant treatment, tooth extraction and endodontic treatment. By preoperative knowledge of these findings may useful to plan the treatment and to prevent complications of mandibular surgery.

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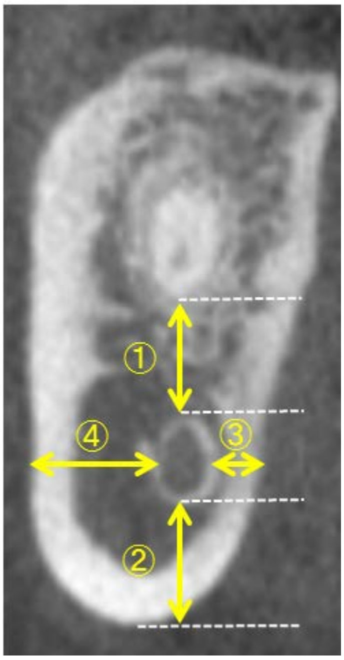
Fig.1

The distance to the mandibular canal from the apex of the second molar, inferior cortex, lingual cortex and buccal cortex of the mandible.

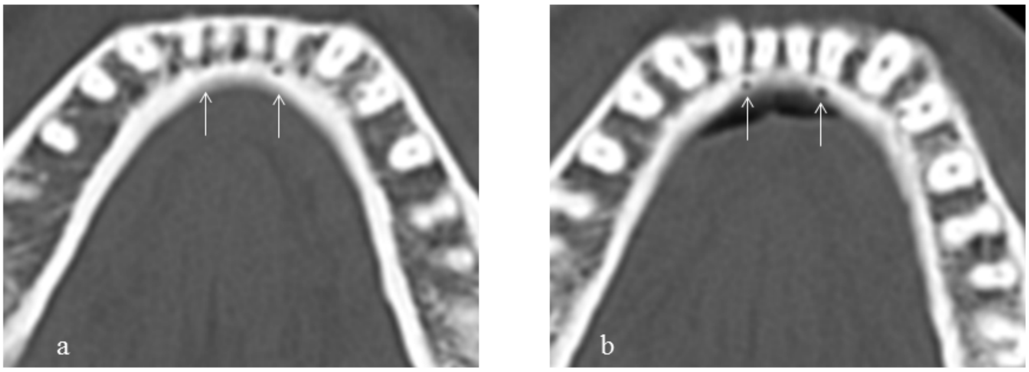


① the distal root apex of the mandibular second molar (A) to superior cortical bone of the mandibular canal (MC): A-MC, ② the inferior cortical border of the mandible to the inferior cortex to the MC: I-MC, ③ the lingual cortical border of the mandible to the MC: L-MC, and ④ the buccal cortical border of the mandible to the MC: B-MC.

Fig. 2 The sagittal CT image of the mandibular nutrient canal in 52-year-old female patient.

The mandibular nutrient canal between the left central and lateral incisors (white arrow) proceeds to the lingual plate of the cortical bone on sagittal CT image.

Fig. 3 The axial CT images of the mandibular nutrient canals in 52-year-old female patient.



The nutrient foramen (white arrows) appears between the central and lateral incisors on CT axial image.

Table 1. Age related differences of the distance to the mandibular canal from the apex of the second molar, inferior cortex, lingual cortex and buccal cortex of the mandible the (the right and the left sides were combined).

	Male n=68		
	Group I n=26 (mean±SD)	Group II n=21 (mean±SD)	Group III n=21 (mean±SD)
A to MC (mm)	2.40±2.69 **	3.42±2.53	4.01±2.27 **
I to MC (mm)	7.19±2.06	7.53±2.18	7.19±1.74
L MC (mm)	2.40±1.40	2.13±1.17	1.94±0.94
B to MC (mm)	5.81±1.69	5.96±1.78	5.38±1.27
	Female n=87		
	Group I n=25 (mean±SD)	Group II n=32 (mean±SD)	Group III n=30 (mean±SD)
A to MC (mm)	1.40±1.69 *, **	2.58±2.21 *	3.36±2.97 **
I to MC (mm)	6.62±1.73	7.32±2.61	6.98±1.80
L to MC (mm)	3.00±1.11	2.52±1.00	2.72±1.24
B to MC (mm)	6.26±1.51	6.04±1.35	5.83±1.38

Group I is younger than 21 years, group II was between 21-40 years and group III was older than 40 years. In males, the distance between A-MC was significantly shorter in group I than in group III (***P*<0.01).

In females, the distance between A-MC was significantly shorter in group I than in group II and in group III (group I vs group II; **P*<0.05, group I vs group III; ***P*<0.01).

Table 2. Differences related to the side of the mandible

	Male n=68	
	Right (mean±SD)	Left (mean±SD)
A to MC (mm)	3.16±2.56	3.02±2.66
I to MC (mm)	7.38±1.91	7.15±2.10
L to MC (mm)	2.32±1.14	2.18±1.29
B to MC (mm)	4.94±1.57 **	5.70±1.64**
	Female n=87	
	Right (mean±SD)	Left (mean±SD)
A to MC (mm)	2.62±2.65	2.41±2.36
I to MC (mm)	6.82±1.57	7.18±2.58
L to MC (mm)	2.72±1.07	2.75±1.19
B to MC (mm)	5.91±1.60 **	6.06±1.36 **

In males, the distance between B-MC was significantly shorter in right than in left (***P*<0.01).

In females, the distance between B-MC was significantly shorter in right than in left (***P*<0.01).

Table 3. Gender differences related to the side of the mandible.

	Male right n=68 (mean±SD)	Female right n=87 (mean±SD)
A to MC (mm)	3.16±2.56 **	2.62±2.65 **
I to MC (mm)	7.38±1.91	6.82±1.57
L to MC (mm)	2.32±1.14	2.72±1.07
B to MC (mm)	4.94±1.57	5.91±1.60
	Male left n=68 (mean±SD)	Female left n=87 (mean±SD)
A to MC (mm)	3.02±2.66 *	2.41±2.36 *
I to MC (mm)	7.15±2.10	7.18±2.58
L to MC (mm)	2.18±1.29 **	2.75±1.19 **
B to MC (mm)	5.70±1.64	6.06±1.36

In mandibular right, the distance between A-MC was significantly longer in males than in females (***P*<0.01).

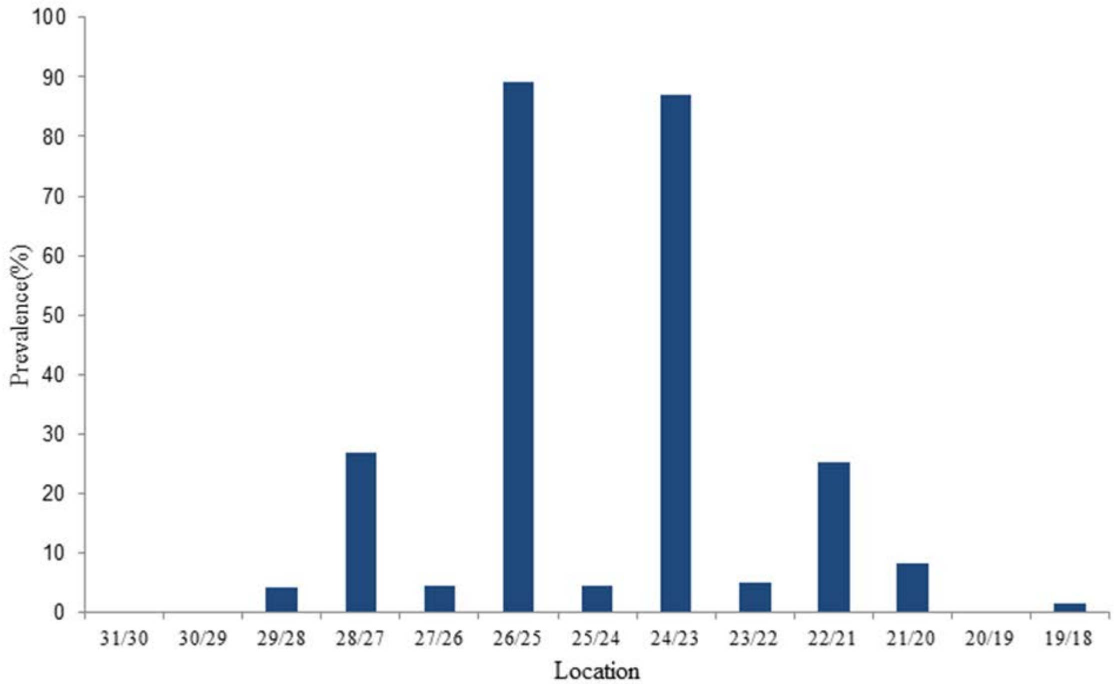
In mandibular left, the distance between A-MC was significantly longer in males than in females. The distance between L-MC was significantly shorter in males than in females (***P*<0.01).

Table 4. Gender differences related to the A-MC distance (the right and the left sides were combined).

	Male n=68	Female n=87
Apex to MC (mm)	3.21±2.61 **	2.51±2.51 **
I to MC (mm)	7.29±2.01	7.00±2.14
L to MC (mm)	2.18±1.21	2.73±1.13
B to MC (mm)	5.73±1.62	6.03±1.41

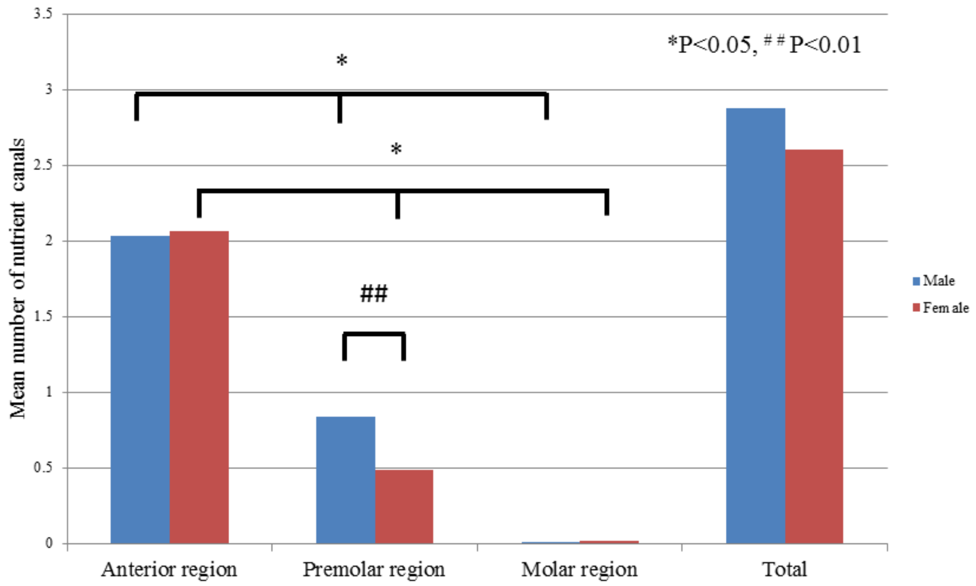
The distance between A-MC was significantly longer in males than in females (***P*<0.01).

Fig. 4 Prevalence of nutrient canals in the mandible.



Canals are found most frequently between the right central incisor (25) and the lateral incisor (26) and between the left central incisor (24) and the lateral incisor (23). Teeth in this figure are numbered according to the Universal Numbering System.

Fig. 5 The mean number of nutrient canals in different regions of the mandible.



Differences were statistically analyzed using the Mann-Whitney U test (*) and the Steel-Dwass test (#). *$P < 0.05$; ##$P < 0.01$.

Fig. 6 Correlation between age and the mesio-distal diameter of the nutrient canals between the right central and lateral incisors.

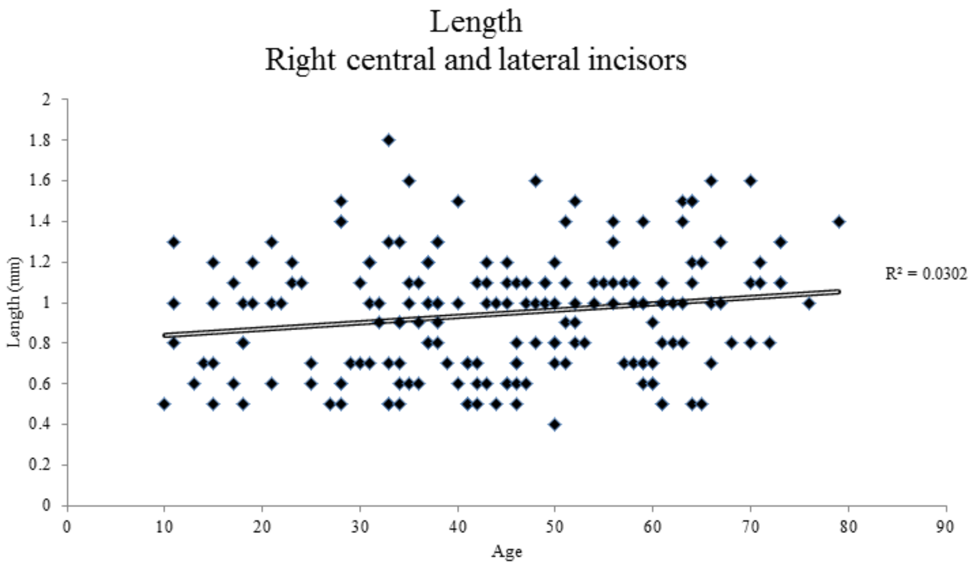


Fig. 7 Correlation between age and the bucco-lingual diameter of the nutrient canals between the right central and lateral incisors.

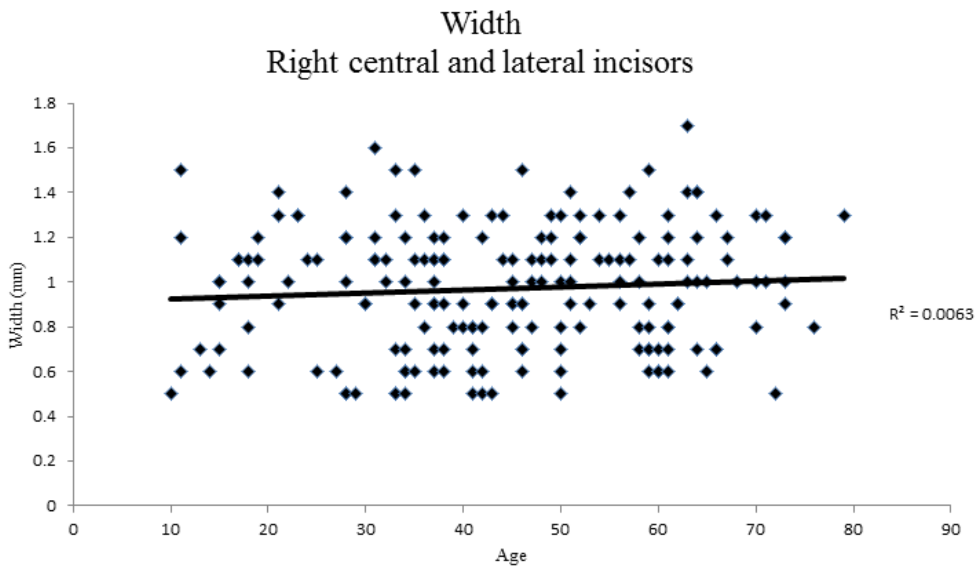


Fig. 8 Correlation between age and the mesio-distal diameter of the nutrient canals between the left central and lateral incisors.

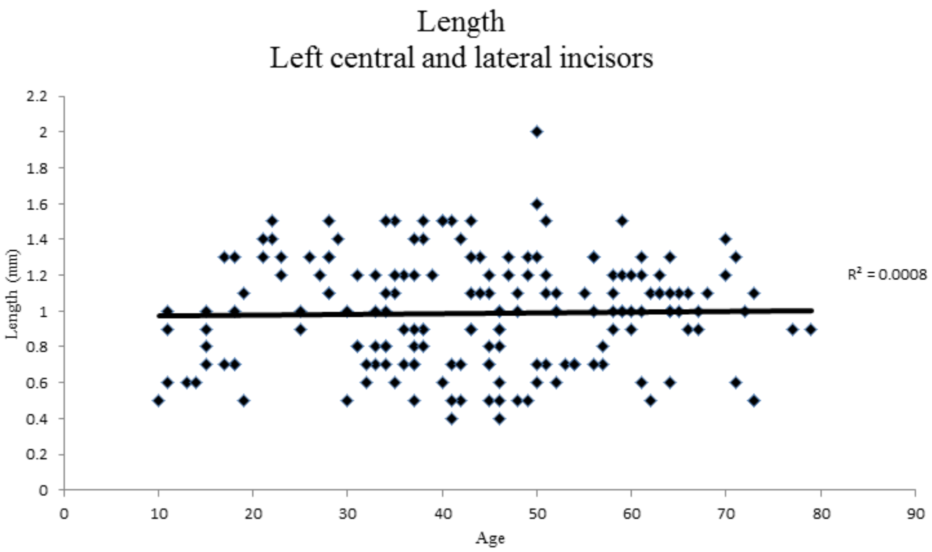


Fig. 9 Correlation between age and the bucco-lingual diameter of the nutrient canals between the left central and lateral incisors.

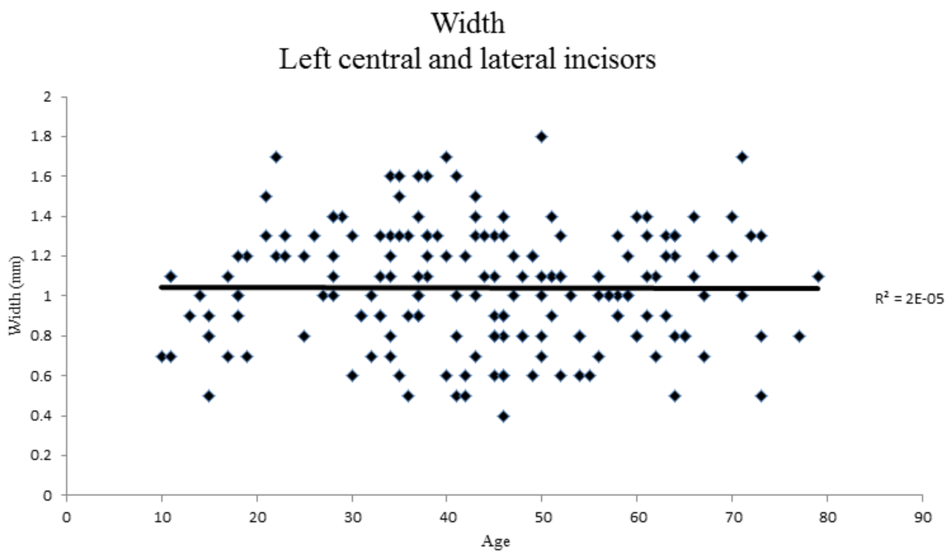
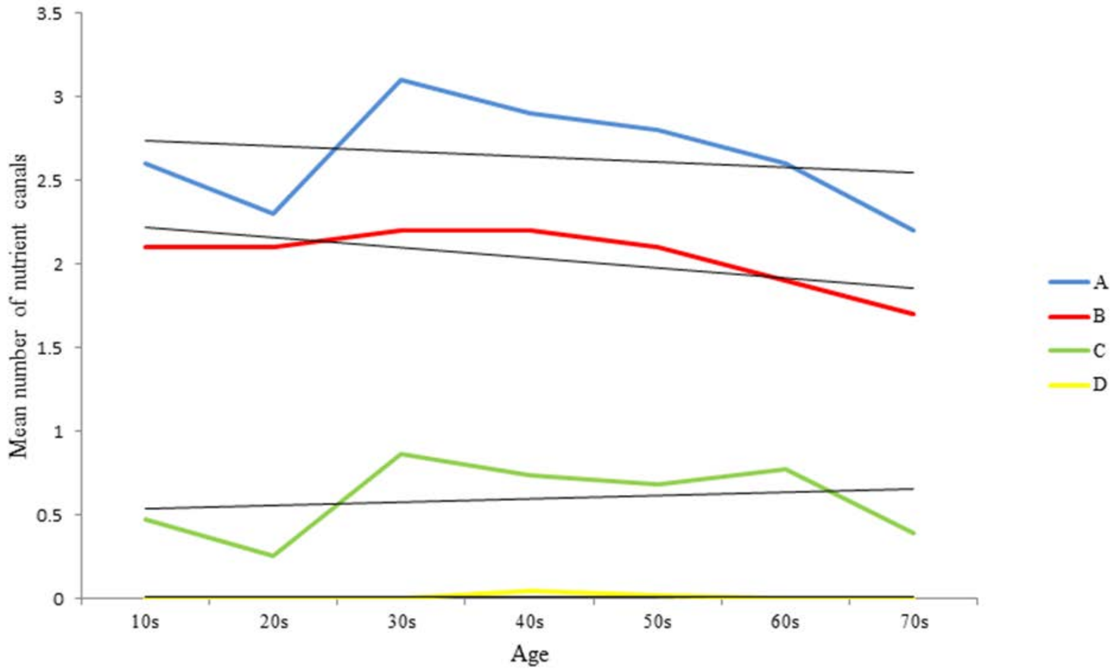


Fig. 10



Relationship between age and the mean number of nutrient canals in (A) the entire mandible; (B) the anterior region; (C) the premolar region; and (D) the molar region.