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Spatial relationship between the root apices of mandibular teeth and the mandibular canal on CBCT reconstructions

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ABSTRACT

Introduction: Close relationship between root apices of mandibular teeth and the mandibular canal is related to the risk of complications involving the inferior alveolar nerve.

The objective of this study was to determine the spatial relationship of the root apices of mandibular teeth in relation to the mandibular canal.

Materials and methods: On the frontal plane of 300 cone beam computed tomography (CBCT) scans, the spatial mutual position and measurements of the vertical and horizontal distance between the tooth root apices and the mandibular canal were determined.

Results: For 23 root types out of 26, the roots of the mandibular teeth were found to exhibit a buccal orientation. The exceptions were the mesial roots of the 1st molars and the mesio-buccal roots of the 2nd molars on the right side, which showed a lingual orientation. The distances were measured for 2053 roots. For the teeth on the left side, the mean measurements ranged 0.23–3.77 mm for buccal roots, and the measurement was 0.21 mm for roots located lingually. For the teeth on the right side, the mean measurements ranged 0.38–2.93 mm for buccal rootsand 0.11–0.32 mm for lingual roots.

Conclusions: The predominantly buccal orientation of the root apices of the mandibular teeth in relation to the mandibular canal was demonstrated.

Keywords: cone beam computed tomography; CBCT; inferior alveolar canal; inferior alveolar nerve; volumetric computed tomography.

INTRODUCTION

The state of the knowledge on treatment techniques and technology in various branches of dentistry is undergoing continuous development [1]. In order for treatment effects to be associated with the lowest possible risk of complications, they must be preceded by correct diagnosis that requires detailed diagnostic procedures [2]. Based on the diagnosis, a treatment plan is created. When it comes to physical examination, it is hard to obtain the relevant data without the latest technology. Although X-rays were discovered in 1895 [3], the devices and digital information processing methods currently used in diagnostic radiology show how much progress has been made since Wilhelm Roentgen reported the existence of "X-rays". From the classical X-ray, through the layered X-ray, to computed tomography (CT), the development of radiological examination techniques has progressed remarkably [4]. The pinnacle of the use of ionizing radiation in diagnosis is 3-dimensional tomographic imaging modalities, which include helical CT, multislice CT, and cone beam computed tomography (CBCT). The latter is widely used in dentistry, both in daily clinical practice and as a research tool [5].

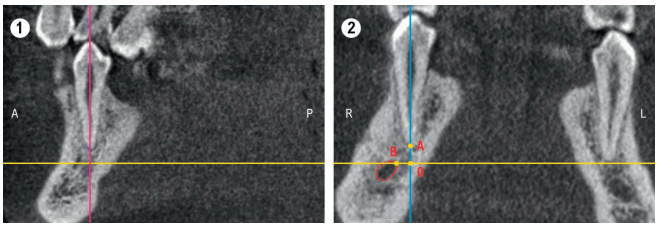
The purpose of this study was to determine the bucco-lingual relationship between the root apices of mandibular teeth and the mandibular canal and the horizontal distance between these structures based on CBCT images. This is important in the context of complications of endodontic or surgical treatment from the inferior alveolar nerve, which is one of the structures present in the mandibular canal. In the case of surgical treatment, the greatest risk is related to mechanical nerve injury. During endodontic treatment, there is an increased risk of chemical irritation from canal rinsing or filling agents or thermal irritation from thermal methods of root canal filling [6, 7, 8, 9, 10]. To the authors' knowledge, this is the first study to examine this issue using CBCT as a tool and measurement method.

MATERIAL AND METHODS

Upon Pomeranian Medical University Bioethics Committee approval (KB-0012/159/05/17), a database of CBCT scans was used for the study. The scans belonged to patients who were referred most frequently for implant treatment planning between 2009–2018 and were characterized by the presence of at least 1 canine, premolar, or molar in the mandible with a fully formed root and a closed apical foramen, without periapical lesions or signs of root resorption, and a visible mandibular canal lumen. Studies with the resolution of >0.25 mm and studies with visible mandibular posttraumatic lesions or artefacts that prevented a valid measurement were excluded from the research.

Three hundred CBCT scans obtained with a Gendex GXCB-500 (KaVo Kerr, Charlotte, North Carolina, USA) were included in the study. The exposure parameters were: 120 kV, 5 mA, exposure

time 3–7 s, resolution 0.25–0.125 mm, and imaging field from 85 mm × 60 mm to 85 mm × 133 mm. Measurements were performed independently by 2 investigators using multiplanar reconstruction in RadiAnt DICOM Viewer 5.5.0 software (Medixant, Poznan, Poland) on a personal computer running Windows 10 (Microsoft Corporation, Redmond, Washington, USA) and a 3.69 MP resolution monitor. First, the mandibular canal was localized on the frontal plane, starting from the mental foramen to the mandibular foramen. Each tooth type was recorded. Tooth root morphology was analyzed and assigned to one of the following groups: single root (S), mesial root (M), distal root (D), mesio-lingual root (ML), mesio-buccal root (MB), disto-lingual root (DL) or disto-buccal root (DB). Grid lines were placed on the frontal and sagittal reconstructions to align the image along the long axis of each root. A point A corresponding to the root apex was marked on the frontal plane, then point B closest to point A on the oval formed by the mandibular canal. A horizontal line was then drawn, passing through point B, and a vertical line, passing through point A. The lines intersected at right angles at point 0. The vertical distance from the root apex to the mandibular canal was described as A0, and the horizontal distance was described as B0 (Fig. 1). The average of both investigators' measurements was taken for calculation.



A – anterior; P – posterior; R – right; L – left

FIGURE 1. Sagittal (1) plane, frontal (2) plane, in the frontal plane the point A corresponding to the root apex was determined, then point B closest to point A on the oval formed by the mandibular canal (red dashed line). A horizontal line was then drawn, passing through point B, and a vertical line passing through point A. The lines intersected at right angles at point 0. The vertical distance from the root apex to the mandibular canal was described as A0, and the horizontal distance was described as B0

The positions of root apices in relation to the mandibular canal were presented as mean values with standard deviations (SD). They were compared between males and females using Mann–Whitney U test and Spearman rank correlation coefficient (Rs) was used to analyze their correlations with age. Differences and correlations with $p < 0.05$ were considered statistically significant.

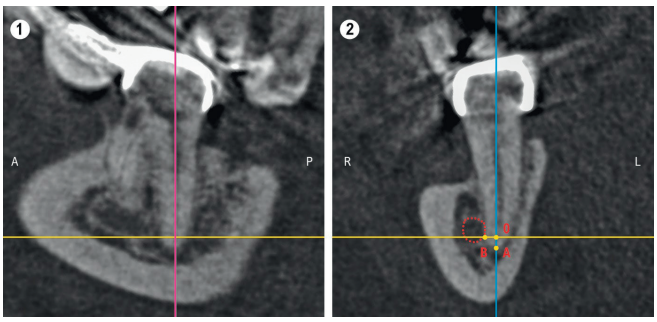
RESULTS

Cone beam computed tomography scans belonging to 167 women and 133 men aged 20–79 years old were analyzed. Of the 2053 roots that were measured, only 12 were recorded whose apices were in positions for which the distance A0 took negative values (Tab. 1), which meant that the position of the tooth apices was below the mandibular canal (Fig. 2). In the vast majority of cases, this distance took positive values and determined the position of the apices above the mandibular canal (Fig. 1). The average vertical distances between the root apices and the mandibular canal ranged from 1.58 mm for the 3rd molars on the right side and 5.11 mm for the 1st molars on the right side (Tab. 2). The analysis of the measurements revealed a significant positive association between distance and male sex for the 2nd premolars on the right side, mean for males was 4.97 ±2.9, for females 3.54 ±2.5. And a positive correlation between distance and age for the mesial and distal roots of the 1st, 2nd and 3rd molars on both the right and left sides (Rs: 36M = 0.25, 36D = 0.22, 37M = 0.27, 37D = 0.34, 38M = 0.27, 38D = 0.4, 46M = 0.24, 46D = 0.23, 47M = 0.3, 47D = 0.34, 48M = 0.39, 48D = 0.45). For the above root types, the measured distance was greater in males than in females and increased with age.

TABLE 1. Mean distances (mm) from both investigators' measurements between the root apices of the mandibular teeth and the mandibular canal on cone beam computed tomography frontal sections for individual cases located below the mandibular canal

Tooth no., root type	Age	Sex	Mean distance (mm)
36M	21	female	2.87
36D	21	female	5.32
38S	37	female	2.14
38S	58	male	1.015
38S	36	female	0.755
38D	26	female	1.25
45S	62	female	0.4
45S	21	female	1.52
46D	21	female	1.58
47M	57	female	1.56
47D	57	female	1.02
47D	35	male	0.19

M – mesial; D – distal; S – single



A – anterior; P – posterior; R – right; L – left

FIGURE 2. Sagittal (1) plane, frontal (2) plane, example in which the root apex is below the mandibular canal; in the coronal plane point A corresponds to the root apex, point B is closest to point A on the oval formed by the mandibular canal (red dashed line)

TABLE 2. Mean vertical (A0) and horizontal (B0) distances between the mandibular canal and the tooth apices on cone beam computed tomography frontal sections (negative B0 values for teeth in the third quadrant indicate a lingual position, negative B0 values in the fourth quadrant indicate a buccal position)

Tooth no., root type	No. of roots	Mean distance A0 (mm)	SD (mm)	Mean distance B0 (mm)	SD (mm)	Position of root apices in relation to the mandibular canal
34S	7	3.37	1.2	0.23	1.09	+
35S	206	4.29	2.36	0.53	1.28	+
36M	133	5.05	2.37	−0.21	1.21	–
36D	135	4.69	2.36	0.26	1.15	+
37S	28	3	2.52	1.3	1.9	+
37M	178	3.23	2.22	1.7	1.26	+
37D	178	2.56	2.17	1.94	1.45	+
37ML	3	2.02	2.56	3.2	0.37	+
38S	31	2.23	2.32	2.08	2.02	+
38M	83	2.6	2.48	2.48	1.77	+
38D	90	2.05	2.49	2.23	1.64	+
38ML	8	2.79	2.48	3.77	3.04	+
38MB	8	2.78	2.65	1.01	1.24	+
45S	189	4.18	2.76	−0.39	1.19	+
46M	133	5.11	2.2	0.32	1.06	–
46D	140	4.83	2.37	−0.38	1.3	+
47S	22	3.19	2.17	−1.56	1.37	+
47M	163	3.06	2.22	−1.31	1.5	+
47D	158	2.59	2.23	−1.54	1.5	+
47ML	7	3.4	2.71	−2.37	1.3	+
47MB	7	3.36	2.77	0.11	0.85	–
48S	23	1.58	1.66	−1.23	1.61	+
48M	61	2.76	2.24	−2.03	1.73	+
48D	51	2.55	2.04	−2.23	1.5	+
48ML	4	3.32	1.82	−2.93	2.51	+
48MB	4	2.2	1.88	−1.2	1.11	+

S – single; M – mesial; D – distal; ML – mesio-lingual; MB – mesio-buccal; "+" – buccal; "–" – lingual; SD – standard deviation

The sign of the number describing the distance B0 indicates the buccal or lingual position of the tooth root apices in relation to the mandibular canal. Based on the average measurements of the 2 investigators for 23 root types out of 26, the roots of the mandibular teeth were found to exhibit a buccal orientation on average. The exceptions were the mesial roots of the 1st molars and the mesio-buccal roots of the 2nd molars on the right side, which showed a lingual orientation on average. Mean distances measured in the frontal plane along a horizontally drawn line (B0) for the teeth on the left ranged 0.23–3.77 mm for buccal roots, and the distance for lingual roots was 0.21 mm. For the teeth on the right side, the mean measurements ranged 0.38–2.93 mm for buccal roots and from 0.11–0.32 mm for lingual roots (Tab. 2). The measurements showed no positive association with sex, but for the mesial and distal roots of the left 2nd molar, distal right 2nd molar, mesial buccal right 2nd molar, and the single root of the right 3rd molar, there was a statistically significant association with age (Rs: 37M = 0.22, 37D = 0.22, 47D = 0.22, 47MB = 0.76, 48S = 0.48). For the above root types, the measured distance increased with age.

DISCUSSION

The main feature that was analyzed was the mutual spatial relationship between the root apices of the mandibular teeth and the mandibular canal in a bucco-lingual relationship, as there was little variation in the results obtained in the vertical axis. Less than a half percent of the measurements obtained indicated that the location of the tooth apices was below the mandibular canal. These 12 teeth belonged to 6 females and 2 males aged 21–62 years old (Tab. 1). This can be considered a rare deviation from the norm, which is the presence of tooth roots above the mandibular canal. When analyzing these exceptions, it is important to note that they occurred with the 2nd premolars on the right side, the 1st and 2nd molars on the right

side, and the 1st and 3rd molars on the left side. The distances at which the examined structures were located ranged from 0.81 mm for the distal root of the right 2nd molar to 5.32 mm for the distal root of the left 1st molar (Tab. 1). The overwhelming majority of results indicated that the position of the tooth apices above the mandibular canal had a correlation between distance and sex for the 2nd premolars on the right side. The fact that this correlation was observed for only 1 tooth type, unilaterally, seems to be due to the limited study sample. On the other hand, the correlation with age, where the measured distance was greater in older individuals, may be associated with the tooth movement observed after the completion of bone development [11].

Analyzing the bucco-lingual relationship, the individual results no longer present such a high degree of homogeneity. However, when averaged among the individual roots, one can see the regularity that the root apices of mandibular teeth usually locate buccally in relation to the mandibular canal; the exceptions are the mesial roots of the 1st molars on the right and left sides and the mesio-buccal roots of the right 2nd molars. It should be noted, however, that for these 3 roots, the measured mean distance did not exceed 0.32 mm for the mesial roots of the right 1st molar and was only 0.11 mm for the mesio--buccal roots of the right 2nd molars, given that the distance values ranged from 3.77 mm for the mesio-lingual roots of the left 3rd molars to the aforementioned 0.11 mm.

The first attempt to use CBCT to examine the position of the mandibular canal in relation to the root apices of the 1st molar and points located on the mandibular surface was the work of Simonton et al. in 2009 [12]. The authors took 14 measurements of the shortest distance for each of 200 teeth in the parasagittal plane: 7 in the mesial root and 7 in the distal root; (1) distance between the buccal lamella and the most buccal point of the root at 3 mm coronal from the apex; (2) distance between the lingual lamella and the most lingual point of the root at 3 mm coronal from the apex; (3) width from the lingual margin to the buccal margin of the mandible at 3 mm coronal from the apex; (4) distance from the buccal lamina to the buccal surface of the mandibular canal measured perpendicular to the long axis of the root; (5) distance from the lingual lamina to the lingual surface of the mandibular canal measured perpendicular to the long axis of the root; (6) total bucco-lingual width of the mandible measured through the diameter of the mandibular canal; (7) the shortest distance between the apex of the tooth root and the wall of the mandibular canal. They thus initiated a series of publications based on a similar measurement method using the parasagittal plane in determining the shortest distance of the tooth apices to the mandibular canal [13, 14, 15]. However, the researchers focused on other groups of teeth and used different exposure parameters. Later publications also used measurements determining the shortest distance between the mentioned structures, but they used reconstructions in the frontal [16, 17] or sagittal [18, 19] plane. Methodologies for studying the anatomical relationships of the mandible have evolved. A study by Thai researchers measured the vertical distance of the apices of the 2nd premolars and the 1st and 2nd molars in the frontal plane [20]. To increase the precision of the measurements and their clinical usefulness, subsequent studies determined the distance between the tooth root apices and the highest point on the bone plate forming the mandibular canal on various reconstructions [21, 22, 23].

A sophisticated measurement methodology was used in the study by Chong et al., where the distance from the apex of each root of 134 second molars was analyzed in the frontal plane. After identifying the oval corresponding to the cross-section of the mandibular canal, a transverse line tangent to the highest point of the mandibular canal was established, followed by a vertical line perpendicular to the transverse line. The vertical axis (*y*) determined the distance from the apex of the tooth root to the point of intersection of the 2 lines, and the transverse axis (x) determined the distance from the point of intersection of the lines to the highest point lying on the cross-section of the mandibular canal. The measured distance between the root apex and a point on the cross-section of the mandibular canal was mathematically calculated using the Pythagoras' theorem applied to the x and y values for each root [21].

However, the measurement method described above did not take into account the spatial arrangement of the structures. In the case of 2-dimensional radiological examinations, standards are used for positioning the patient or a specific part of the body so that the examination result is as reproducible as possible and key body fragments for diagnosis or treatment control are imaged. Three-dimensional studies allow, through the use of software, far-reaching processing of reconstructions arising from multiple 2-dimensional scans. This offers great diagnostic possibilities but requires high accuracy to maintain the repeatability of measurements. The positioning of the patient during the examination itself, which varies from device to device, can affect repeatability. There is also the matter of exposure parameters, imaging field, and examination resolution that are not standardized and depend on the factory settings of the CT or the decision of the person responsible for the examination. Another controversial factor is the arbitrary spatial placement of reconstructions. From a diagnostic perspective, the advantage of CBCT is the possibility of evaluating a fragment of tissue or organ with great accuracy, without the risk of overlapping structures in any perspective. When the emphasis is placed on the repeatability of measurements, it requires a precisely defined plane on which the measurement is made and the mutual position of planes at which the reconstruction is evaluated. The authors of the mentioned studies [12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23] used tomographs with different resolutions and different exposure parameters; they also divided their study samples into groups because of the diverse factors they chose, which makes it difficult to compare the results of individual studies due to differences in the measurement methods [24].

Depending on the anatomical structure on which the study is focused, authors define reference points between which measurements will be taken. Within the mandibular anatomical structures, these are bony points located on the mandibular

external compact lamina [12, 23], on the compact lamina forming the lumen of the mandibular canal [13, 20, 23], on the compact lamina forming the lumen of the mental foramen [25], or anatomical points such as the apices of tooth roots [12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23].

All of the above-mentioned publications focused on defining the relationships between the described structures as the distances between them, yet they said little about spatial relationships, in the sense of mutual positioning of over, under, buccal and lingual.

The results that are presented in this article demonstrate that in the qualified study sample, with the mandibular positioning method adopted, the correct position of most mandibular tooth root apices in relation to the mandibular canal is above the canal and buccal to its course. To our knowledge, there is no research on the interrelationships of the described structures performed in accordance with the measurement methodology adopted in this publication. This is related to the lack of comparative material. The relatively small study sample and low racial diversity of the patients whose CBCT scans were analyzed are the limitations of this study (all participants were Caucasian). These factors prompt the need for continued research into the issues raised in this publication.

CONCLUSIONS

Despite the growing number of studies on the mandibular structure using CBCT as a research tool, there are still issues that need to be investigated or require using another research method.

This publication confirms the predominant position of root apices above the mandibular canal and buccally, which may be helpful information for clinicians, especially for microsurgical procedures in the context of avoiding inferior alveolar nerve complications.

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