ORIGINAL ARTICLE

UDC: 616.314
DOI: https://doi.org/10.2298/VSP210517075B

Root and canal-specific features of maxillary first molars with fused roots

Specifičnosti korenova i kanala prvih maksilarnih molara sa spojenim korenovima

Katarina Beljić-Ivanović, Branislav Karadžić

University of Belgrade, Faculty of Dental Medicine, Department of Restorative Dentistry and Endodontics, Belgrade, Serbia

Abstract

Background/Aim. Maxillary first molars are one of the most challenging teeth for endodontic therapy. There are certain disparities in the number of roots and canals and canal interrelationships within the same root, particularly those with fused roots. The aim of the study was to assess *ex vivo* features of roots, root canals, and canal walls in maxillary first molars with fused roots. **Methods.** Out of the total of 366 maxillary first molars, 64 extracted maxillary first molars with fused roots were included in the study using cone-beam computed tomographic and microscopic examining. Tooth dimensions at the level of pulp chamber floor, number, location and distance between orifices, number and canal morphology, canal wall thickness, and features of apical *foramina* were examined and measured. **Results.** The incidence of maxillary first molars with root fusion was 17.5%, of which 60.0% was palatal fused to distobuccal root. At the level of the pulp chamber floor, the bucco-palatal dimension was significantly larger at 10.4 mm than M-D with 7.0 mm. Four canal orifices were detected in 65.6%, with the shortest distance of 1.95 mm between MB1 and MB2. In fused roots, two or three canals most frequently correlated strongly with the number of major apical *foramina*. No fusion of canals was found in fused roots. The thinnest canal wall in the mesiobuccal and distobuccal fused root was mesial with 1.25 mm, and distal with 1.31 mm, while for the palatal root, the thinnest was the palatal wall with 1.97 mm. Two or three large apex *foramina* were registered with a significant correlation with the number of canals in the fused root. **Conclusion.** The most frequent type of fusion was between the palatal and distobuccal roots. Bucco-palatal dimension at the level of the pulp chamber floor was significantly larger than the mesiodistal, with the shortest inter-orifice distance between the MB1 and MB2 orifice. The number of canals was either two or three, coinciding with the number of major apical *foramina*. There was no fusion of the canals in fused roots. The thinnest canal wall was either mesial or distal.

Key words:
maxilla; molar; multidetector computed tomography; tooth root.

Apstrakt

Uvod/Cilj. Prvi maksilarni molari su među najkompleksnijim zubima za endodontsko lečenje. Postoje određene razlike i odstupanja u morfologiji njihovih kanala, posebno kod maksilarnih prvih molara sa spojenim korenovima. Cilj rada bio je da se *ex-vivo* ispitaju morfološke specifičnosti korenova, korenskih kanala i njihovih zidova, kod prvih maksilarnih molara sa spojenim korenovima. **Metode.** Od ukupno 366 maksilarnih prvih molara, primenom kompjuterizovane tomografije konusnog snopa i stereo-mikroskopa, u studiju je uključeno i proučeno 64 zuba sa spojenima korenovima. Izmereni su i analizirani dimenzije zuba na nivou dna komore pulpe, broj, oblik, lokacija i rastojanje između ulaza u kanale, broj i morfologija kanala, debljina zidova kanala u spojenim korenovima i karakteristike apeksnih otvora (*foramina*). **Rezultati.** Učestalost spajanja korenova registrovana je kod 17,5% prvih maksilarnih molara, od čega je kod 60% zuba palatinalni koren bio spojen sa distobukalnim korenom. Bukopalatinalna dimenzija od 10,4 mm bila je značajno veća od meziodistalne, koja je iznosila 7,0 mm. Kod 65,6% zuba otkrivena su 4 ulaza u kanale, a najkraće rastojanje od 1,95 mm bilo je između MB1 i MB2 ulaza. Kod fuzionisanih korenova dva ili tri kanala su najčešće snažno korelirali sa brojem velikih apeksnih otvora. U spojenim korenovima nije registrovana fuzija kanala. Najtanji zid bio je ili mezijalni, sa prosečnom vrednošću od 1,25 mm ili distalni sa 1,31 mm, osim u palatinalnom spojenom korenu, sa palatinalnim zidom značajno veće debljine – 1,97 mm. Registrovana su dva ili tri velika apeksna otvora, uz značajnu korelaciju sa brojem kanala u spojenom korenu. **Zaključak.**

Correspondence to: Katarina Beljić-Ivanović, University of Belgrade, Faculty of Dental Medicine, Department of Restorative Dentistry and Endodontics, Rankeova 4, 11000 Belgrade, Serbia. E-mail: katarinabeljicivanovic@yahoo.com

Najčešće spajanje registrovano je između palatinalnog i distobukalnog korena. Bukopalatinalna dimenzija na nivou dna pulpne komore bila je značajno veća od mezio-distalne, a najmanje rastojanje izmereno je između MB1 i MB2 ulaza u kanale. Broj kanala bio je najčešće dva ili tri, uz direktnu korelaciju sa brojem velikih apeksnih otvora. Spajanje korenova nije pratilo spajanje kanala. Najtanji dentinski zid svih kanala bio je ili mezijalni ili distalni.

Ključne reči:
maksila; molari; tomografija, kompjuterizovana, multidetektorska; zub, korenski kanal.

Introduction

Besides adequate and thorough knowledge about usual external and internal root canal morphology and its possible variations [1], it is of utmost importance to evaluate each individual case for aberrant anatomy and to identify any morphological variation before and during the endodontic procedure of such teeth [2, 3]. Clinicians often have to treat teeth with unusual anatomy of their root canal system and atypical configurations, which is a constant challenge for diagnosing and managing such teeth [4]. Maxillary first molars are one of the most complex and challenging teeth in endodontology and endodontic practice, known as "possibly the most treated, least understood, posterior teeth" [5]. There are certain disparities and aberrations in their root morphology and configuration of the canal system, particularly in maxillary first molars with fused roots, mostly presented in various case reports and experimental studies but less in clinical evaluations or retrospective assessments [6–8]. Those variations have been attributed to differences in either ethnicity, i.e., national background, gender, or differences in study design, evaluation method, or sample size and structure [9–12].

The very beginning of the 21st century brought Cone-Beam Computed Tomography (CBCT), or Digital Volumetric Tomography (DVT), into endodontic practice, which provides three-dimensional images in a noninvasive and nondestructive way [13]. Importantly, it has been proved as a more accurate method for precise and detailed detection of root canal morphology in clinical conditions, especially in the maxillary region [9, 14, 15]. Literature that deals with the use of CBCT for revealing root canal anatomy presents and describes wide variations in morphological features of maxillary first molars, but reports are mostly focused on the number and configuration of mesiobuccal (MB) root canals, supernumerary roots, or root canals [16–19].

There are quite a few articles targeting maxillary first molars with fused roots, with or without C-shaped canals, often describing their endodontic treatment, and they are generally confined to case reports [20–22]. However, incidence, type of root fusion, root and root canal relation to other anatomical parameters that may influence and interfere with the endodontic treatment of maxillary first molars with fused roots have been presented in a few studies and literature reviews [6, 7, 23–25].

The aim of the study was to evaluate *ex vivo* anatomomorphological characteristics of the roots, root canals, and dentin canal walls in maxillary first molars with fused roots with the aid of CBCT and light microscopy.

Methods

The materials used for this study were human maxillary first molars collected from individuals of both genders, 25–60 years of age, and from both sides of the jaw. According to the Approval of the Ethics Board of the Faculty of Dental Medicine, University of Belgrade, Serbia (No 36/30 from December 21, 2011), after signing the written consent, patients' teeth were extracted due to advanced periodontal disease, prosthetic or orthodontic demands, or extremely poor prognosis for endodontic treatment. Teeth with cracked or fractured roots, apical root resorption, massive coronal destruction or restorations, as well as those undergoing endodontic treatment, were excluded from the further procedure. Tooth samples were then stored in a 3% NaOCl solution (Parcan, Septodont, Saint-Maur-des-Fossés, France) for one hour to dissolve periodontal ligaments. After cleaning the root surface, all teeth were stored in a saline solution with 0.2% thymol at 4 °C temperature until examining procedure.

From the total number of 366 collected maxillary first molars, only those teeth with two or all roots entirely fused from the cement-dentinal junction (CDJ) to the very apical portion were included in this study. Coronal preparation, trepanation, and removal of the entire pulp chamber roof were done using high-speed round diamond bur with a water spray as a coolant. Occlusal walls were flattened using diamond cylindrical bur (F011 series; Dentsply/Maillefer, Ballaigues, Switzerland), and lateral walls were refined using conical carbide bur with passive tip (EndoZF.G; Dentsply/Maillefer). Ultrasonic tips Start-X1 and Start-X2 (Dentsply/Maillefer) were used to remove dentin deposits interfering with canal orifices, which were then identified and marked using × 3.5 loupes and Micro Opener tip #1 (Dentsply/Maillefer) with neither widening nor reshaping from the original. Respecting the original root canal diameter, K-Reamers size 0.6, 0.8, and 1.0 (C-Pilot, VDW GmbH, Munich, Germany) were used to establish patency of each canal until the tip of the instrument was visible at the anatomical *foramen* under × 3.5 magnification.

After completing this procedure, four teeth were placed with their roots in a round block of impression paste Zeta Plus (Zhermak, Rovigo, Italy) with the pulp chamber floor parallel to the horizontal plane and mounted at the CBCT device with the aid of a laser positioner. CBCT examination was performed using Scanora® 3DX (Soredex, Tuusula, Finland) with a small field of view 50 x 50 mm, with a voxel size of 100 µm, 90 kVp, 10 mA. All data were analyzed in the OnDemand 3D Application computer program (CyberMed, Seoul, South Korea). Images were processed and analyzed from axial, sagittal, and coronal planes. All measurements for each tooth sample and at each predetermined point along the roots from the coronal to the apical portion of each canal were conducted and recorded by two independent examiners, both endodontic specialists trained in CBCT techniques.

At the pulp chamber floor level, a quadrangle was drawn around each cross-section of the scan tangenting the most prominent spot on the mesial (M), buccal (B), distal (D), and palatal (P) borderline. Dimensions were measured in four directions: a) mesiodistal (M-D); b) bucco-palatal (B-P); c) mesiopalatal-distobuccal (MP-DB); d) distopalatal-mesiobuccal (DP-MB) (Figure 1a). Centers of each consecutive orifice were connected by straight lines, which formed a multi-angle, presenting a specific “dentin map” at the pulp chamber floor. The number, shape, and distance between the centers of the orifices and the “dentin map” for each tooth were recorded on CBCT scans. Distance between two neighboring centers was measured with a precision of 0.01 mm (Figure 1b). The angle between two lines connecting three consecutive orifices was expressed in degrees (Figure 1c). That enabled to determine precise orientation and localization of the canal orifices.

The statistical analysis contained a correlation between the following parameters: a) number of orifices to the number of anatomical *foramina*; b) number of orifices to the number of canals; c) number of canals to the number of anatomical *foramina*; d) distance between MB1 and MB2 canal orifices in MB fused root.

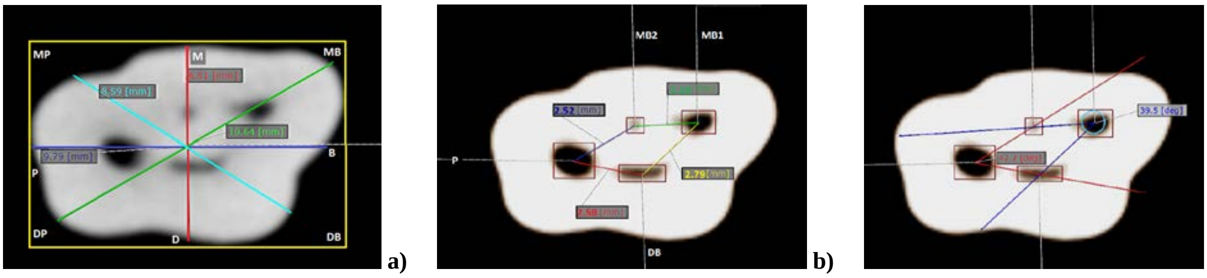
Canal morphology within the same root was categorized according to Vertucci classification [5]. To determine the thickness of the canal dentin, wall measurements were conducted on axial CBCT sections at each consecutive 100 µm of each fused root. Values were grouped as averages for the coronal (c), middle (m), and apical (a) levels for each root canal. Measurements were done from four directions: a) (M), b) (B), c) (D), and d) (P).

Following canal irrigation with 2 mL of 3% NaOCl solution tooth was impressed and centered with its coronal portion in a cube of red wax to accomplish the best position to visualize each individual *foramen*. The location and number of apical *foramina* were registered and photographed under a microscope with × 24 magnification.

Statistical methods contained descriptive analysis and the Spearma's correlation analysis that reflects the level of agreement. Inter-rater reliability was analyzed with Cohen’s kappa-test for two examiners. All data were computed using the software package SPSS 20 (IBM Corporation).

Results

Of the total 366 maxillary first molars, 294 (80.3%) had three distinctive roots, 64 (17.5%) were with fused roots, and eight (2.2%) teeth were with four separate roots. Types of fusion are presented in Table 1 and Figure 2. The most



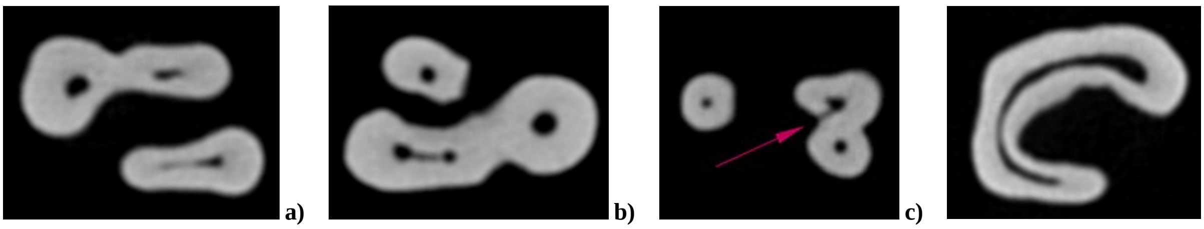
a) b) c)

Fig 1 – Tooth, distances, and angles between canal orifices at the level of pulp chamber floor:
a) measuring lines and tooth dimensions at the pulp chamber floor from various directions (M – mesial, B – buccal, P – palatal, D – distal, MB – mesiobuccal, DB – distobuccal, DP – disto-palatal, MP – mesio-palatal);
b) measuring lines and distances between canal orifices (MB1 – MB first canal, MB2 – MB second canal);
c) lines connecting three consecutive orifices with angles between the two.

Table 1
Type of fusion of maxillary first molar roots

Type of fusion	n (%)
All in one	2 (3.1)
DB - P	38 (59.4)
MB - P	16 (25.0)
MB - DB	8 (12.5)

DB – distobuccal; P – palatal; MB – mesiobuccal.



a) b) c) d)

Fig. 2 – Types of root fusion in maxillary first molars: a) all roots and canals fused into a single one (C-shape configuration); b) palatal fused to distobuccal (DB) root; c) palatal fused to mesiobuccal (MB) root; d) MB fused to DB root.

frequent root was P fused to DB (Figure 2a), followed by P to MB (Figure 2b), and MB to DB root (Figure 2c) with significant differences among all those types (Table 1; $p < 0.001$). Consecutively, P showed the strongest tendency towards fusion and MB root the least. Of 64 fused-rooted maxillary first molars, only two had all roots fused into one (Figure 2 d).

At the pulp chamber floor level, the dimension was significantly larger than MD (Table 2; $p < 0.05$). The diagonal dimension MB-DP was larger compared to MP-DB with a significant difference (Table 2; $p < 0.05$). Analysis of the orifice shape showed that circular or oval shape was found to be absolutely dominant, with a few crevice-like orifices. Four canal orifices were found in two-thirds of fused rooted maxillary first molars with a high statistical difference from other variations (Table 3; $p < 0.001$). The sides and angles of the quadrangle formed by connecting those four orifices were measured. The longest distance was between the P-DB and P-MB2 orifice, while the shortest distance was between the MB1-MB2 orifice (Table 4; $p < 0.005$). The largest angle was between neighboring lines connecting centers of MB1-MB2 with MB2-P canal orifices, and the smallest was between MB2-P and P-DB sides (Table 4; $p < 0.001$).

Either two or three canals were found in the same percent with dominant prevalence over four or five, with a high statistical difference (Table 5; $p < 0.001$). No canal fusion was detected in any of the fused roots. Canal configuration, according to Vertucci classification [5], could not be accomplished in 26 of 64 fused roots (Figures 3a and 3b).

Table 5 presents the distribution of configuration types with significant differences between types IV, VI, and VIII ($p < 0.01$). In 40% of fused roots, pulpo-periodontal

Table 2

Tooth dimensions (mm) at the level of the pulp chamber floor

Dimension	Mean ± SD	Median	Min–Max
BP	10.42 ± 0.78	10.36	9.03–11.67
MD	7.06 ± 0.41	7.04	6.27–7.97
MB-DP	11.52 ± 0.52	11.42	10.61–12.72
MP-DB	8.68 ± 1.09	8.64	6.66–10.51

BP – bucco-palatal; MD – mesiodistal; MB – mesiobuccal; DP – distopalatal; DB – distobuccal; SD – standard deviation; Min – minimum; Max – maximum.

Table 3

Distribution of the number of orifices at the pulp chamber floor

Number of orifices	n (%)
1	2 (3.1)
2	4 (6.2)
3	9 (14.1)
4	42 (65.7)
5	5 (7.8)
6	4 (3.1)

Table 4

Distance between orifice centers (mm) and angles formed by sides of a quadrangle (°)

Distance/Sides	Mean ± SD	Median	Min–Max
Distance			
MB1-MB2	1.95 ± 0.45	1.95	1.29–3.04
MB2-P	3.62 ± 0.85	3.82	2.27–4.68
P-DB	3.63 ± 0.78	3.46	2.60–5.19
DB-MB1	2.69 ± 0.51	2.92	1.60–3.36
Angle			
MB1-MB2→MB2-P	143 ± 13.68	141.00	121–170
MB2-P → P-DB	37 ± 7.05	36.50	25–51
P-DB→ DB-MB1	117 ± 15.07	117.00	85–137
DB-MB1→MB1-MB2	62 ± 10.95	60.00	44–90

MB – mesiobuccal; P – palatal; DB – distobuccal; SD – standard deviation; Min – minimum; Max – maximum.

Table 5

Distribution of the number of canals in fused roots and Vertucci-type classification [5]

Parameter	n (%)
Number of canals in a fused root	
2	30 (46.9)
3	30 (46.9)
4	2 (3.1)
5	2 (3.1)
Vertucci-type	
IV	18 (47.4)
VI	10 (26.3)
VIII	10 (26.3)

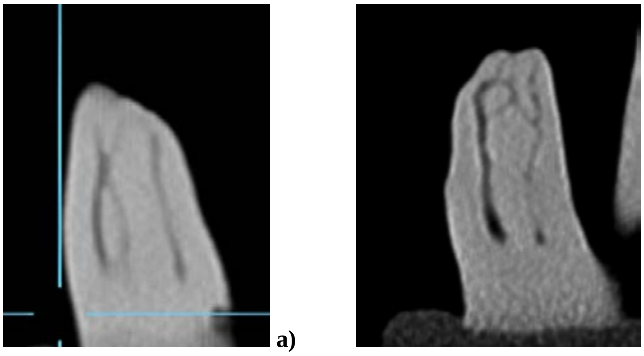
communications (PPCs) were detected at different levels of root canals (Figures 4 a–d).

Table 6 shows that the thinnest canal wall of the P fused root was mesial, followed by distal and palatal, but with no significant difference ($p > 0.1$). The buccal wall had the greatest thickness with a highly significant difference from the other three ($p < 0.001$).

The thinnest canal walls of the DB fused root were mesial and distal, with no mutual differences (Table 7; $p > 0.1$). The buccal wall was slightly thicker than the latter two (Table 7; $p < 0.05$), while the palatal wall was the thickest at all three levels, with a highly significant difference from the other three ($p < 0.001$).

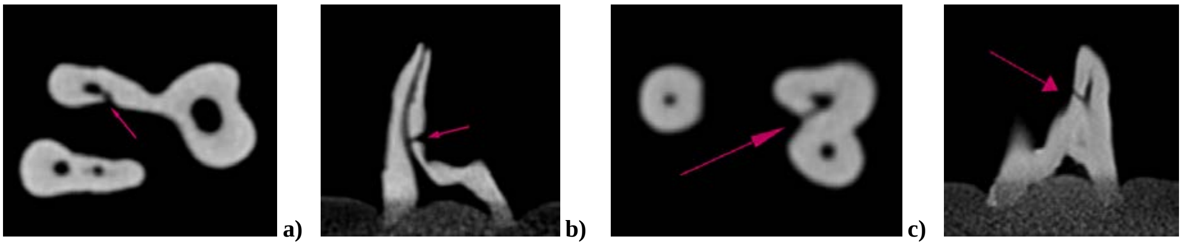
The smallest values of dentin wall thickness for the MB1 canal in the MB fused root at all three levels were found for the distal one (Table 8). There was no statistical difference between values for distal, mesial, and buccal walls (Table 6; $p > 0.1$). The thickest wall was the palatal at all three levels, with significant differences from the other three (Table 8; $p < 0.005$).

Mesial and distal walls of the MB2 canal were significantly thinner than the other two at all three levels of the MB fused root (Table 9). The thickest wall was the buccal one, with a significant difference from the latter two (Table 9; $p < 0.001$). Values for the palatal wall of the MB2 canal were significantly different from the distal and mesial ($p < 0.05$), as well as from the buccal one ($p < 0 .01$).



a) b)

Fig. 3 – Feature of fused roots with unclassified canals upon Vertucci types [5]: a) sagittal section of fused roots with specific morphology which could not be included in Vertucci [5] classification; b) sagittal section of fused roots with specific unclassified canals, particularly in the apical third, with extreme variability of canal pathways.



a) b) c) d)

Fig. 4 – Cone-beam computed tomography (CBCT) sections presenting pulpo-periodontal communications (PPCs) specific for maxillary first molars with fused roots: a) axial section showing palatal (P) to distobuccal (DB) type of root fusion with PPCs in DB root canal with mesio-palatal (MP) orientation (arrow); b) sagittal section of the same PPCs at the coronal to mid-root location (arrow); c) axial scan of mesiobuccal (MB) to DB type of root fusion with PPCs in MB root canal (arrow); d) sagittal scan of the same MB root showing mid-root located PPCs (arrow).

Table 6

Values of the canal wall thickness (mm) in palatal (P) fused root

Localization	Mean ± SD	Median	Min–Max
C m	2.04 ± 0.22	2.03	1.72–2.58
C d	2.10 ± 0.13	2.03	2.00–2.42
C b	6.56 ± 0.40	6.60	6.03–7.14
C p	2.24 ± 0.27	2.20	1.58–2.63
M m	1.69 ± 0.38	1.73	1.15–2.44
M d	1.79 ± 0.19	1.87	1.21–2.01
M b	6.47 ± 0.65	6.60	5.60–7.76
M p	1.74 ± 0.17	1.75	1.44–2.15
A m	1.31 ± 0.25	1.29	0.88–1.87
A d	1.32 ± 0.22	1.35	0.72–1.60
A b	5.57 ± 1.10	5.32	3.50–7.67
A p	1.47 ± 0.34	1.52	0.77–2.31

C – coronal; M – middle; A – apical; m – mesial; d – distal; b – buccal.
SD – standard deviation; Min – minimum; Max – maximum.

Table 7

Values of the canal wall thickness (mm) in distobuccal (DB) fused root

Localization	Mean ± SD	Median	Min–Max
C m	1.18 ± 0.28	1.24	0.72–1.70
C d	1.43 ± 0.18	1.40	1.13–1.72
C b	2.25 ± 0.14	2.29	2.02–2.58
C p	6.34 ± 0.47	6.36	5.56–7.44
M m	1.05 ± 0.20	1.15	0.57–1.29
M d	1.18 ± 0.13	1.20	0.86–1.39
M b	2.02 ± 0.15	2.01	1.72–2.27
M p	6.31 ± 0.60	6.31	5.46–7.25
A m	1.01 ± 0.18	0.95	0.80–1.41
A d	0.97 ± 0.21	0.95	0.72–1.43
A b	1.50 ± 0.28	1.58	1.10–1.87
A p	5.75 ± 0.82	5.72	3.47–7.52

C – coronal; M – middle; A – apical; m – mesial; d – distal; b – buccal; p – palatal; SD – standard deviation; Min – minimum; Max – maximum.

Table 8

Values of the wall thickness for MB1 canal (mm) in mesiobuccal (MB) fused root

Localization	Mean ± SD	Median	Min–Max
C m	1.42 ± 0.26	1.38	1.15–2.03
C d	1.42 ± 0.26	1.45	1.00–1.87
C b	1.93 ± 0.18	1.89	1.60–2.44
C p	4.46 ± 0.34	4.50	3.44–4.86
M m	1.23 ± 0.13	1.23	0.86–1.44
M d	1.20 ± 0.14	1.17	1.00–1.43
M b	1.66 ± 0.26	1.72	1.29–2.09
M p	3.53 ± 0.70	3.31	2.30–4.39
A m	1.18 ± 0.21	1.12	0.87–1.63
A d	1.05 ± 0.20	1.09	0.71–1.41
A b	1.26 ± 0.22	1.27	1.00–1.67
A p	2.66 ± 0.841	2.73	1.15–3.68

C – coronal; M – middle; A – apical; m – mesial; d – distal; b – buccal; p – palatal; SD – standard deviation; Min – minimum; Max – maximum.

Table 9

Values of the wall thickness for MB2 canal (mm) in mesiobuccal (MB) fused root

Localization	Mean ± SD	Median	Min–Max
C m	1.15 ± 0.23	1.15	0.72–1.60
C d	1.19 ± 0.18	1.27	0.86–1.43
C b	4.26 ± 0.69	4.24	2.30–5.36
C p	2.15 ± 0.59	2.04	1.28–4.02
M m	1.04 ± 0.16	1.00	0.72–1.32
M d	0.98 ± 0.19	0.99	0.57–1.30
M b	3.51 ± 0.49	3.31	2.87–4.30
M p	2.01 ± 0.28	1.96	1.65–2.58
Am	0.99 ± 0.18	1.00	0.57–1.32
A d	0.95 ± 0.18	0.97	0.72–1.36
A b	2.55 ± 0.85	2.78	1.15–3.52
A p	1.74 ± 0.46	1.72	1.15–2.60

C – coronal; M – middle; A – apical; m – mesial; d – distal; b – buccal; p – palatal; SD – standard deviation; Min – minimum; Max – maximum.

Half of the fused roots had two, and approximately one-third had three major apical *foramina* (Table 10) (Figures 5a and 5b). There was a strong direct correlation between the number of major *foramina* and the number of canals in fused roots (Tables 10 and 5; Rho = 0.509; $p < 0.003$). Table 10 also presents that more than half of fused roots had no minor, i.e., accessory *foramina*, and one-quarter had one accessory *foramen* (Figures 5a and 5c).

Table 10

Distribution of the number of *foramina* on apices of fused roots with respect to the diameter

Number of *foramina*	n (%)
major	
1	6 (9.4)
2	34 (53.1)
3	22 (34.4)
4	2 (3.1)
minor	
0	36 (56.2)
1	16 (25.0)
2	6 (9.4)
3	2 (3.1)
4	4 (6.2)

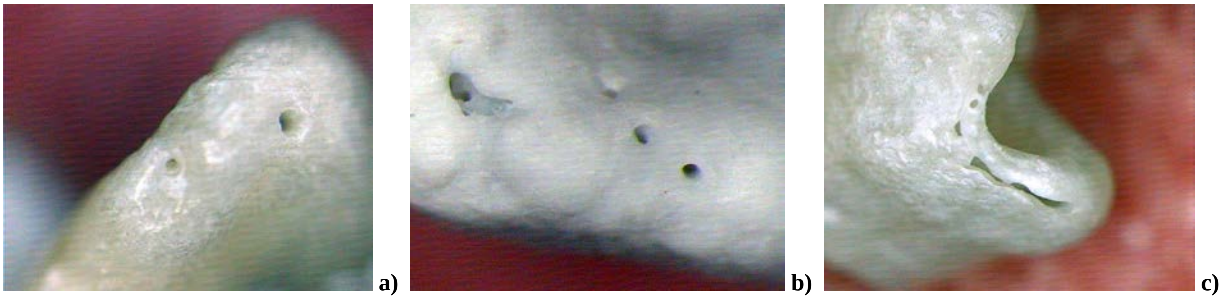


Fig. 5 – Stereo-microscopic images of specific anatomical *foramina*: a) minor, i.e., accessory *foramen* (left) and major anatomical *foramen* (right) on the apex of mesiobuccal (MB) fused to distobuccal (DB) root; b) huge anatomical *foramen* (left) with two anatomical *foramina* (right) on the apex of palatal (P) fused to MB root; c) long and curved crevice-like anatomical *foramen* (right) and three minor *foramina* at the apex of C-shaped fused roots.

Cohen's kappa-test showed high inter-examiner reliability of 94% (kappa-test > 0.90).

Discussion

Material for this *ex vivo* study was primarily chosen with respect to the previous study in the same population [26, 27], aiming to reveal wide scope of different morphological features and variables that characterize first maxillary molars with fused roots. There are quite a few research articles dealing with this topic, as well as case presentations, mostly accompanied by endodontic treatment or retreatment of those teeth [8, 21, 28, 29].

CBCT and scanning technique used in this study enabled to detect and register not only anatomical details of the main canal but also the presence of accessory canals, intercanal communications, their dividing and deviations, to follow their entire paths along different roots and measure the thickness of the canal walls from different aspects at various levels of the root. All those anatomical features are more complex and specific in teeth with fused than in teeth with three distinctive, i.e., separate roots. Micro-CT, even though proven as the most precise method in presenting morphological details of the root canal, is limited only to extracted teeth [30, 31]. Results of several retrospective studies of the morphology of maxillary first molars and quite a few case reports showed high precision of CBCT in revealing tiny details of their root canal anatomy both *ex vivo* and, more importantly, *in vivo*, in clinical conditions [32-34]. Bauman et al. [35] showed that the voxel size has a great impact on the accuracy in detecting multiple canals of first maxillary molars, stressing that only 60.3% of canals were detected when voxel size was 400 µm, and 93.3% with a voxel size of 125 µm for the same group of teeth. Therefore, the CBCT technique with a voxel size of 100 µm was used in this study to detect and describe important and specific morphological details in fused roots of maxillary first molars with root fusion.

The term fused root is defined as two or more roots that are united either through the deposition of cementum from the cement-enamel junction to the root apex [9], formed in the course of an individual's life, or with more histological and anatomical support, as the result of an alteration in the development of the Hertwig epithelial root sheath in the furcation area of multirooted tooth [34]. Moreover, the presence of extra canals in maxillary first molars is more frequent than the presence of fused roots, which is supported by the statement of Vertucci [20] that root fusion in three-rooted teeth is an exception from the usual anatomy.

This study showed that of the total number of examined maxillary first molars, 17.5% were found to be with fused roots. Studies that have been conducted using different methods as well as review articles and case reports, showed a wide range in the incidence of this anatomical entity, rising from none [15, 36] to 23.9% [9]. The incidence of fused roots was found to be significantly lower in the first than in the second maxillary molars, from an extreme difference of 0.7% vs.

10.7% [23] or 1.4% vs. 23.9% in Chinese patients [9]. The same incidence with almost the same values but with less reciprocal differences of 7% vs. 21% and 7.1% vs. 25.2% was found in Saudi Arabians [24] and Portuguese individuals [34], respectively. Marcano-Caldera et al. [37] found in Columbian patients an extremely high incidence of root fusion in maxillary molars of 23.3% in the first vs. 57.7% in the second, with a lower difference ratio between the two. High percentages and variations, even within the same population, could be attributed to the fact that different authors presumably applied different criteria for defining three-rooted first maxillary molars. Silva et al. [38] stated that differences could also be found due to an erroneous assessment method of morphological details. All authors pointed out the impact of ethnicity, i.e., race origin, on the prevalence and anatomical characteristics of fused roots in maxillary first molars, which was one of the main reasons to conduct this study, specifically on the Serbian population.

Age factor may affect the detection of the root canals and their morphology; therefore, patients between 25–50 years old were included in this study, as in the previous survey [26], revealing no influence of age on examined characteristics of maxillary first molars with fused roots. Mohara et al. [39] used individuals 18–45 years old, similar to this study, while Naseri et al. [40] included patients with a very wide age range from 10–70 years old, and both found no statistical difference between patients' age. The late result may be attributed to the sample size and higher concentration of individuals in particular age groups. However, most studies generally showed that as age progresses, the number of detected MB2 canals decreases [41].

Considering the influence of gender on the incidence of fused roots, this study showed no difference in the results concerning patients' sex, which coincides with results by Naseri et al. [40] and Lee et al. [41]. Conversely, Ross and Evanchik [42] reported a 13% higher incidence of root fusion in females than in males in the multinational group, which was supported by findings of Martins et al. [34] for Portuguese individuals. Marcano-Caldera et al. [37] found in that Latin Americans, 64.1% of all fused roots belonged to women, similar to results by Al-Shehri et al. [43], who found 71.4% of root fusion in females in the Saudi population.

No significant difference between left- and right-sided teeth was found in this study, confirmed by Zheng et al. [44] and previously cited authors. Zhang et al. [15] found that 84% of maxillary molars had perfect symmetry in the root and canal morphology of homonym teeth on the opposite side, similar to Felsypremila et al. [32], with 77.5% of bilateral symmetry of root fusion. In Saudi Arabians, Mashyajkhy et al. [24] found no statistical difference between patients' sex and left- and right-sided teeth in fused rooted maxillary molars. On the contrary, in the same subpopulation, Al-Shehri [43] reported a significantly higher prevalence of fused roots in the right-sided teeth. Those findings support the statements that anatomical variations between different and within the same morphological group of teeth could be affected besides ethnic factors by the sample characteristics or the varieties in methodology.

Most articles that have studied root fusion paid either no attention to the type of fusion [25, 40, 42, 45] or presented only rare cases [8, 22, 46]. Since the palatal root dominates on periapical radiography, it is clear why fusion between the massive palatal and one of the buccal roots is very hard to detect. Thus, the CBCT technique with a voxel size of 100 µm was used as it revealed the entire anatomy from all three scanning planes enabling the detection of many tiny details. The most frequent fusion was found between the P and DB roots (Table 1). Marcano-Caldera et al. [37] confirmed this result with a frequency of 58.9%, while Mashyajkhy et al. [24] in Saudi Arabians and Martins et al. [34] in Portuguese found an even higher incidence of P-DB fusion with 66.7% and 85.3%, respectively. On the contrary, among Malaysians, Al-Kadhim et al. [47] reported only the MB-DB type of fusion, which supports the impact of the ethnic foundation of root morphology, and further justifies the use of a specific national population in this study.

Of 64 maxillary first molars with root fusion, only two had all roots fused into one conical shape (Table 1). Single-rooted maxillary first molars are considered an extreme anatomical feature or certain root anomaly and have been presented as rare cases [29, 48–50] or with no incidence of such entity [24, 51]. Conversely, Marcano-Caldera et al. [37] found 16.1% of maxillary first molars with all three roots joined into a single cone-shaped, and when the authors added teeth with all three fused roots associated with one or more lateral grooves, the percentage rose to 21%. There is an enormous discrepancy between those results and the result from the present study, as well as the findings by other authors [23, 52], confirming diversity in criteria when defining root fusion.

The results revealed that the first maxillary molars with fused roots have irregular shapes and contours at their cross-section at the pulp chamber floor level and different levels of their roots. Additionally, there is a geometric inability to define measuring spots and lines that hinder or interfere with obtaining the most precise and reproducible measurements. In order to overcome those problems, a quadrangle was drawn around the axial section of each CBCT scan at the pulp chamber floor level with lines tangenting the four most prominent spots on the contour borderline, accompanied by two diagonal lines. Measurements showed that the B-P dimension was significantly larger than M-D ($p < 0.005$). Diagonally oriented diameter MB-DP was the largest one, significantly larger than the MP-DB diagonal line ($p < 0.05$), determining the cross section in a trapezoid-like shape. Quite a few authors reported on the external and internal anatomy of maxillary molars [39, 44, 45] with no information on tooth dimensions at the pulp chamber floor level, particularly not in maxillary first molars with fused roots, as presented in this study.

Results showed that a regular oval shape of the canal orifice was found in the absolute majority of cases, and the rest were crevice-like or a combination of those two, with no information in the available literature on these characteristics of maxillary first molars with fused roots. Information on the number of orifices in maxillary first molars with fused roots may be found in fewer case reports, mostly associated with their endodontic management [8, 28, 46, 50].

Considering inter-orifice distances, the most intriguing and clinically important is the one between MB1 and MB2. There are a few reports for maxillary first molars with three separate roots, and values varied from 1.20 mm detected by Spagnuolo et al. [53] to 2.90 mm presented by Magat and Hakbilen [54]. Keçeci et al. [55] measured an MB1-MB2 distance of 1.97 mm, which strongly coincides with the 1.95 mm found in this study (Table 4). Differences in those results have been attributed to variations in race, sample and voxel size, and/or experimental methods. The review of the current literature revealed no study on special geometry formed by canal orifices in maxillary first molars with fused roots. Presented results have clinical relevance when a dentist tends to negotiate canal orifices in maxillary first molars with fused roots, stressing the great importance of having proper insight into the "dentin map", particularly on MB1 and MB2 relation, which is the first instance a practitioner meets when approaching root canal instrumentation.

Roots formed by the fusion of two or more roots showed specific morphological features different from a single root, and thus they were considered a separate anatomical unit. Complex morphology complicates and hinders canal instrumentation and thus decreases the success rate of endodontic therapy, as proved by many case reports [17, 40, 41, 51]. The same incidence of either two or three canals was detected in fused roots, and no case was found with one single canal (Table 5), indicating that the fusion of the roots is not associated with the fusion of the canals. That was confirmed by Tian et al. [56] and Mashyajkhy et al. [24], with only 4.5% and 8.3% of merged canals in DB-P type of root fusion, respectively. On the contrary, Martins et al. [34] found multiple merging canals in 25%, where the confluence position was usually between the DB root and the palatal canal. Several case reports presented two rooted maxillary first molars with two canals, where the buccal orifice was the large one, most likely C-shaped, and another was a regular single palatal canal [8, 55, 57]. All those authors estimated that root fusion is not always accompanied by the merging of the canals, confirming the results from this study.

Of all multiple canals detected in fused roots, 40% could not be classified according to Vertucci types, which emphasizes their complexity (Figure 3a, b). Interestingly, PPCs were revealed in the significant incidence of 40% of all fused root canals, irrespective of the type of fusion. PPCs have always been detected on the furcation aspect of the fused root, meaning that any ingress of noxious stimuli through PPCs will inevitably cause either inter-radicular bone lesion or, vice-versa, pulp pathology. Depending on location and diameter, PPCs could complicate and cause the failure of endodontic and periradicular treatment, particularly due to the lack of their precise revealing and detection on the periapical radiographs. Therefore, CBCT should be applied whenever there is a hint of PPCs' presence. Those findings couldn't be discussed since there is no information in the available literature.

At the same apex of the fused root, there were *foramina* of various diameters, and the numerical threshold for the major (large) *foramen* was defined to be 0.3 mm and over [58], while below that value, they were classified as small, i.e., accessory *foramina*. On the apices of fused roots, more than half were with two, and one-third with three large anatomical *foramina*. The degree of correlation showed a direct and strong correlation between the number of canals and the number of major apical *foramina* in fused roots (Rho = 0.509; $p < 0.003$), indicating that the larger the number of major *foramina*, the larger the number of canals was in the "curtain-shaped" fused root. Importantly, no *foramen* coincides with the anatomic apex. As for accessory *foramina*, more than half of the apices were without any, a quarter was with one, and the rest were with two, three, or four small *foramina*. No analysis of this kind was found in the available literature. The Spearman's correlation coefficient showed no statistically significant difference between the number of canal orifices and the total number of apical *foramina* in maxillary first molars with fused roots (Rho = 0.285; $p = 0.114$). There was a tendency that a higher number of orifices was associated with a higher number of *foramina*, but with low correlation and with no significant differences between those two anatomical entities. Therefore, in clinical situations, a practitioner might predict the number of apical *foramina* upon the clear insight into the number of canal orifices when treating maxillary first molars with fused roots.

During root canal preparation with manual or engine-driven instruments, a certain amount of paracanal dentin is removed, which may often lead to either extreme thinning of walls or to worse complications in the form of strip perforation at any level of the root canal, often followed by microcracks or vertical fractures [59, 60]. The main intention of measuring the canal wall thickness in this study was to reveal critical zones, i.e., critical instrumentation areas for the specific root canal in a fused root, which would help to prevent excessive instrumentation and consequences of such endodontic preparation [6, 59, 60].

In the fused P root, the buccal wall of the canal was three to four times thicker at all three levels than the other three walls since the palatal root was always fused with one of the buccal roots with a huge inter-canal dentine layer. Mesial and distal walls were the thinnest along its entire length; therefore, it is important to bear in mind that this area is potentially a risk zone for extreme thinning, despite the massiveness of the palatal root.

A slightly different situation was with canal walls in a fused DB root, as it was fused most frequently with a P root, with three to five greater dentine thicknesses for the palatal wall. The thinnest wall was mesial at all three levels, with no statistical difference compared to the distal but significantly thinner than the buccal one. Oval canal shape in DB fused root with smaller M-D dimension is exposed to stress on mesial and distal walls as potentially prone to weakening and strip perforation during mechanical instrumentation. No data of such measuring on the palatal and DB root canals in maxillary first molars with fused roots were found in the available literature.

Considering the canal complexity in MB fused root, the dentin wall thickness of the MB1 and MB2 canals has been put in focus. Regardless of the fact whether the MB root was fused to P or the DB root, the thinnest walls around MB1 and MB2 canals were distal and mesial, thus they could be considered a dangerous zone or "critical instrumentation areas" and most prone to procedural errors during their mechanical instrumentation. In contrast to those two, the palatal wall of the MB1 and the buccal wall of the MB2 canal were several times thicker, with very similar values at all three levels. No article particularly dealing with measuring and assessing canal wall thickness in maxillary first molars with fused roots was found. There are a few studies presenting dentin thickness from different aspects around the MB1 and MB2 canal, but only in maxillary first molars with three separate roots. Matus et al. [61] found that mesial and distal walls for MB1 and MB2 canals were the thinnest, with mean values ranging from 0.81 mm to 1.28 mm, which correlates to the values for a fused MB root in this study. Furthermore, the same authors showed the palatal and buccal walls of similar thickness to the values presented in this study. Degerness and Bowles [62] measured mesial and distal walls as the thinnest towards the coronal portion of MB root and emphasized that the average canal wall thickness decreases for one-third on the distal aspect, suggesting this area for a "danger zone" for maxillary molars at the level where MB root joins the crown of the tooth. This statement corroborates the findings by Yoo et al. [63], pointing to the distal wall as the thinnest one for both MB canals and that dentin walls around MB1 are generally thicker than around the MB2 canal, which corresponds to the results from this study. Previous authors also found that the palatal wall of MB1 and the buccal wall of the MB2 canal were approximately three times thicker, which also coincides with the results from this study. Respecting results from this and other articles, weakening of distal and mesial walls in the MB root of maxillary first molars should be avoided, particularly in those with fused roots. Thus, there is little room for procedural errors with an increasing possibility for strip perforation, which might lead to vertical root cracks and fractures. Knowledge and awareness of the presented discrepancy in the wall thickness between distal and mesial on one vs. buccal and palatal canal walls on the other side would help clinicians keep in mind that real thickness is always less than what appears in intra-oral radiographs.

Generally, mesial and distal walls of all fused roots are more sensitive to thinning at mid-root and coronal third due to the greater tapered design of endodontic instruments and specific "brushing motion" during canal preparation with rotary files. That is particularly important for moderately curved canals and in situations where the canal orifice has to be dislocated away from furcation. Therefore, the combination of variously designed canal instruments during preparation sequences could significantly decrease the production of the "dangerous zone" and thus increase the final success of the entire endodontic treatment.

For judging inter-rater reliability regarding all conducted measurements and calculated data, both CBCT scans and micro-photographs, Cohen's kappa test was used [64]. Results showed 94% agreement between the two examiners (κ-test > 0.90). This high inter-rater reliability is to be expected due to standardized and reproducible levels and locations for the detection of each anatomical entity and each of the measurements. The calculating program was calibrated to the precision of 1/10,000 of unit (four decimals), and the final score was shown with two decimals (1/100) in order to present data in a less complicated and confusing manner, with no effect on the accuracy and significance of each value.

It should be emphasized that there were neither studies nor reviews or reports that have been focused on the anatomical details in such variety and on such morphological specificities of maxillary first molars with fused roots as was presented in this study. The collected number of extracted maxillary first molars from patients of Serbian origin was representative when correlated with various studies on other ethnic groups. Due to those facts, only a few comparisons with the findings of other authors have been discussed. However, results from this study may be of great help for endodontic practice and should facilitate clinical diagnosis when one aims to predict which of those canal variations exist in the specific case. Recognizing and revealing major anatomical aberrations using all available recourses, such as CBCT and the operating microscope, is the first step towards more predictable root canal preparation and higher long-term success of endodontic therapy.

Conclusion

Of the total number of maxillary first molars collected from patients of Serbian origin, 17.5% were with fused roots. The most frequent type was P fused to DB root and significantly less P to MB and MB to DB root. At the pulp chamber floor level, the B-P dimension was significantly larger than M-D. The number of canal orifices was four in two-thirds of teeth, with the shortest MB1-MB2 orifice distance and the longest between P-DB orifices. There were either three or two canals in fused roots with a strong correlation to the number of major apical *foramina*. In the vast majority, there was no inter-canal communication. In MB and DB fused roots, the thinnest canal wall was either mesial or distal, while in the P fused root, the thinnest wall was palatal. Those walls are considered critical areas during mechanical instrumentation. CBCT scanning technique with 100 µm voxel size enabled the detection of tiny details and precise measurements. Comparing data from available literature with the results from this study, certain specificities of the anatomical characteristics were shown in maxillary first molars with fused roots within the Serbian population.

R E F E R E N C E S

1. *Bergmans L, Lambrechts P.* Root canal system anatomy. In: *Bergenholtz G, Hørsted-Bindslev P, Reit C,* editors. Textbook of Endodontology, 2nd ed. Oxford: Blackwell Publishing Ltd; 2011. P. 170–80.
2. *Gopikrishna V, Reuben J, Kandaswamy D.* Endodontic management of a maxillary first molar with two palatal roots and a single fused buccal root diagnosed with spiral computed tomography – a case report. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008; 105(4): e74–8.
3. *Song CK, Chang HS, Min KS.* Endodontic management of supernumerary tooth fused with maxillary first molar by using cone-beam computed tomography. J Endod 2010; 36(11): 1901–4.
4. *Bjørndal L, Lasutsten MH, Reit C.* Root canal treatment in Denmark is most often carried out in carious vital molar teeth and retreatments are rare. Int Endod J 2006; 39(10): 785–90.
5. *Vertucci FJ, Haddix JE, Britto LR.* Tooth morphology and access cavity preparation. In*: Cohen S, Hargreaves KM*, editors. Pathways of the Pulp. 9th ed. St.Louis: Mosby Elsevier; 2006. p. 203–16.
6. *Ahmed HM, Abbott PV.* Accessory roots in maxillary molar teeth: a review and endodontic considerations. Austral Dent J 2012; 57(2): 123–31; quiz 248.
7. *Cantatore G, Berutti E, Castellucci A.* Missed anatomy: frequency and clinical impact. Endod Topics 2009; 15(1): 3–15.
8. *Liu J, Que KH, Xiao ZH, Wen W.* Endodontic management of the maxillary first molars with two root canals: A case report and review of the literature. World J Clin Cases 2019; 7(1): 79–88.
9. *Tian* XM, *Yang* XW, *Qian* L, *Wei* B, *Gong* Y. Analysis of the root and canal morphologies in maxillary first and second molars in a Chinese population using cone-beam computed tomography. J Endod 2016; 42(5): 696–701.
10. *Pan* JY, *Parolia* A, *Chuah* SR, *Bhatia* S, *Mutalik* S, *Pau* A. Root canal morphology of permanent teeth in a Malaysian subpopulation using cone-beam computed tomography. BMC Oral Health 2019; 19(14): 1–15.
11. *Nikoloudaki GE, Kontogiannis TG, Kerezoudis NP.* Evaluation of the Root and Canal Morphology of Maxillary Permanent Molars and the Incidence of the Second Mesiobuccal Root Canal in Greek Population Using Cone-beam Computed Tomography. Open Dent J 2015; 9: 267–-2.
12. *Bhuyan AC, Kataki R, Phyllei P, Gill GS.* Root canal configuration of permanent maxillary first molar in Khasi population of Meghalaya: An in vitro study. J Conserv Dent 2014; 17(4): 359–63.
13. *Cotton TP, Geisler TM, Holden DT, Schwartz SA, Schindler WG.* Endodontic applications of cone-beam volumetric tomography. J Endod 2007; 33(9): 1121–32.
14. *Patel S, Horner K.* The use of cone beam computed tomography in endodontics. Int Endod J 2009; 42(9): 755–6.
15. *Zhang R, Yang H, Yu X, Wang H, Hu T, Dummer PM.* Use of CBCT to identify the morphology of maxillary permanent molar teeth in a Chinese subpopulation. Int Endod J 2011; 44(2): 162–9.
16. *Popović M, Živanović S, Vučićević T, Grujović M, Papić M.* Cone-beam computed study of tooth root and canal morphology of permanent molars in a Serbian population. Vojnosanit Pregl 2020; 77(5): 470–8.
17. *Lyra CM, Delai D, Pereira KC, Pereira GM, Pasternak Júnior B, Oliveira CA.* Morphology of Mesiobuccal Root Canals of Maxillary First Molars: a comparison of CBCT scanning and Cross-sectioning. Braz Dent J 2015; 26(5): 525–9.
18. *Kottoor J, Velmurugan N, Surendran S.* Endodontic management of a maxillary first molar with eight root canal systems evaluated using cone-beam computed tomography scanning: a case report. J Endod 2011; 37(5): 715–9.
19. *Kulild JC, Peters DD.* Incidence and configuration of canal systems in the mesiobuccal root of maxillary first and second molars. J Endod 1990; 16(7): 311–7.
20. *Vertucci FJ.* Root canal morphology and its relationship to endodontic procedures. Endod Topics 2005; 10: 3–29.
21. *Song CK, Chang HS, Min KS.* Endodontic management of supernumerary tooth fused with maxillary first molar by using cone-beam computed tomography. J Endod 2010; 36(11): 1901–4.
22. *Shakouie* S, Ghasemi N, Gholizadeh S. Two-rooted maxillary first molars with two canals: a case series. Iran Endod J 2013; 8(1): 29–32.
23. *Kim Y, Lee SJ, Woo J.* Morphology of maxillary first and second molars analyzed by cone-beam computed tomography in a korean population: variations in the number of roots and canals and the incidence of fusion. J Endod 2012; 38(8): 1063–8.
24. *Mashyajkhy M, Chourasia H, Jabali A, Almutairi A, Gambarini G.* Analysis of fused rooted maxillary first and second molars with merged and C-shaped canal configurations: Prevalence, characteristics and correlations in Saudi Arabian population. J Endodod 2019; 45(10): 1209–18.
25. *Cleghorn BH, Christie WM, Dong CC.* Root and root canal morphology of the human permanent maxillary first molar: A literature review. J Endod 2006; 32(9): 813–21.
26. *Beljic-Ivanovic K.* Number, configuration, direction and shape of curvature of root canals in maxillary first molars [thesis]. Belgrade: University of Belgrade, Faculty of Dentistry; 2003. (Serbian)
27. *Beljic-Ivanovic K, Teodorovic N.* Morphological characteristics of mesiobuccal canals in maxillary first molars. Srp Arh Celok Lek 2010; 138(7–8): 414–9.
28. *Fava LR.* Root canal treatment in an unusual maxillary first molar. Int Endod J 2001; 34(8): 649-53.
29. *de la Torre F, Cisneros-Cabello R, Aranguren JL, Estévez R, Velasco-Ortega E, Segura-Egea JJ.* Single-rooted maxillary first molar with a single canal: endodontic retreatment. Oral Surg Oral Med Oral Pathol Oral Radiol Endod, 2008; 106(6): e-66–8.
30. *Acar B, Kamburoğlu K, Tatar İ, Arıkan V, Çelik HH, Yüksel S,* et al. Comparison of micro-computerized tomography and cone-beam computerized tomography in the detection of accessory canals in primary molars. Imag Sci Dent 2015; 45(4): 205–11.
31. *Somma F, Leoni D, Plotino G, Grande NM, Plasschaert A.* Root canal morphology of the mesiobuccal root of maxillary first molars: a micro-computed tomographic analysis. Int Endod J 2009; 42(2): 165–74.
32. *Felsypremila G, Vinothkumar TS, Kandaswamy* S. Anatomic symmetry of root and root canal morphology of posterior teeth in Indian subpopulation using cone beam computed tomography: A retrospective study. Eur J Endod 2015; 9(4): 500–7.
33. *Davis A, Patel S, Foschi F, Mitchel PJ, Manocci F.* The detection of periapicalpathoses using digital periapical radiography and cone beam computed tomography in endodontically retreated teeth – part 2: a 1 year post-treatment follow-up. Int Endod J 2016; 49(7): 623–35.
34. *Martins JN, Mata A, Marques D, Caramês J.* Prevalence of Root Fusions and Main Root Canal Merging in Human Upper and Lower Molars: A Cone-beam Computed Tomography In Vivo Study. J Endod 2016; 42(6): 900–8.
35. *Bauman R, Scarfe W, Clark S, Morelli J, Scheetz J, Farman A. Ex vivo* detection of mesiobuccal canals in maxillary molars using CBCT at four different isotropic voxel dimensions. Int Endod J 2011; 44(8): 752–8.

36. *Gobashy AM, Nagy MM, Bayoumi AA*. Evaluation of root canal morphology of maxillary first molars in an Egyptian population by cone-beam computed tomography. J Endod 2017; 43(7): 1089–92.
37. *Marcano-Caldera* M, *Mejia-Cardona* JL, *Blanco-Uribe* MP, *Chaverra-Mesa* EC, *Rodríguez-Lezama* D, *Parra-Sánchez* JH. Fused roots of maxillary molars: characterization and prevalence in a Latin American sub-population: a cone beam computed tomography study. Restor Dent Endod 2019; 44(2): e16.
38. *Silva EJ, Nejaim Y, Silva AI, Haiter-Neto F, Zaia AA, Cohenca N*. Evaluation of root canal configuration of maxillary molars in a Brazilian population using cone-beam computed tomographic imaging: an in vivo study. J Endod 2014; 40(2): 173–6.
39. *Mohara* NT, *Coelho* MS, *de Queiroz* NV, *Borreau* MLS, *Nishioka*MM, *de Jesus Soares* A, et al. Root anatomy and canal configuration of maxillary molars in Brazilian subpopulation: A 125-μm cone-beam computed tomographic study. Eur J Dent 2019; 13(1): 82–7.
40. *Naseri M, Safi Y, Akbarzadeh Baghban A, Khayat A, Eftekhar L*. Survey of anatomy and root canal morphology of maxillary first molars regarding age and gender in an Iranian population using cone beam computed tomography. Iran Endod J 2016; 11(4): 298–303.
41. *Lee JH, Kim KD, Lee JK, Park W, Jeong JS, Lee Y,* et al. Mesiobuccal root canal anatomy of Korean maxillary first and second molars by cone-beam computed tomography. Oral Surg Oral Med Oral Path Oral Radiol Endod 2011; 111(6): 785–91.
42. *Ross IF, Evanchik PA*. Root Fusion in molars: Incidence and sex linkage. J Periodontol 1981; 52(11): 663–7.
43. *Al-Shehri S, Al-Nazhan S, Shoukry S, Al-Shwaimi E, Al-Sadhan R, Al-Shemmery B*. Root and canal configuration of the maxillary first molar in a Saudi subpopulation: A cone-beam computed tomography study. Saudi Endod J 2017; 7(2): 69–76.
44. *Zheng QH, Wang Y, Zhou XD, Wang Q, Zheng GN, Huang DM*. A cone-beam computed tomography study of maxillary first permanent molar root and canal morphology in a Chinese population. J Endod 2010; 36(9): 1480–4.
45. *Pécora JD, Woelfel JB, Sousa Neto MD, Issa EP*. Morphologic study of the maxillary molars.
46. *Bansal P, Nikhil V, Malhotra P, Singh V*. Maxillary first molar with two roots and two root canals: A rare case report. Endodontology 2018; 30(1): 84–7.
47. *Al-Kadhim AH, Raijon ZA, Malik NA, Jaafar AB*. Morphology of maxillary first molars analyzed by cone-beam computed tomography among Malaysian: Variations among the number of roots and canals and the incidence of fusion. Int Med J Malaysia 2017; 16(2): 33–9.
48. *Gopikrishna V, Bhargavi N, Kandaswamy* D. Endodontic management of a maxillary first molar with a single root and a single canal diagnosed with the aid of spiral CT: a case report. J Endod 2006; 32(7): 687–91.
49. *Chhabra N, Singbal KP, Chhabra TM*. Type I canal configuration in a single rooted maxillary first molar diagnosed with an aid of cone beam computed tomographic technique: A rare case report. J Conserv Dent 2013; 16(4): 385–7.
50. *Desai N, Jadhav RG, Raghavendra SS, Mittal P, Patil G*. Endodontic management of maxillary first molar with type I canal configuration – A rare case report. J Clin Diagn Res 2015; 9(4): ZD16–7.
51. *Jo HH, Min JB, Hwang HK*. Analysis of C-shaped root canal configuration in maxillary molars in a Korean population using cone-beam computed tomography. Rest Dent Endod 2016; 41(1): 55-62.
52. *Martins JNR, Marques D, Mata A, Caramês J*. Root and root canal morphology of the permanent dentition in a Caucasian population: a cone-beam computed tomography study. Int Endod J 2017; 50(11): 1013–26.
53. *Spagnuolo G, Ametrano G, D'Antò V, Formasino A, Simeone M, Riccitello F*, et al. Microcomputed tomography analysis of mesiobuccal orifices and major apical foramen in first maxillary molars. Open Dent J 2012; 6: 118–25.
54. *Magat G, Hakbilen S*. Prevalence of second canal in the mesiobuccal root of permanent maxillary molars from a Turkish subpopulation: a cone-beam computed tomography study. Folia Morphol (Warsz) 2019; 78(2): 351–8.
55. *Keçeci AD*, *Kaya* BU, *Sener E*. Determination of canal orifice coordinates and MB2 incidence of maxillary first molars in a Turkish sub-population. Acta Odon Scand 2014; 72(5): 354–61.
56. *Tian YY, Guo B, Zhang R, Yu X, Wang H, Hu T, Dummer PM*. Root and canal morphology of maxillary first premolars in a Chinese subpopulation evaluated using cone-beam computed tomography, Int Endod J 2012; 45(11): 996–1003.
57. *Martins JN, Quaresma S, Quaresma MC, Frisbie-Teel J*. C-shaped maxillary permanent first molar: a case report and literature review. J Endod 2013; 39(12): 1649–53.
58. *Morfis A, Sylaras SN, Georgopoulou M, Kernani M, Prountzos F*. Study of the apices of human permanent teeth with the use of a scanning electron microscope. Oral Surg Oral Med Oral Path Oral Radiol Endod 1994; 77(2): 172–6.
59. *Berutti E, Paolino DS, Chiandussi G, Alovisi M, Cantatore G, Castellucci A*, et al. Root canal anatomy preservation of WaveOne reciprocating files with or without glide path. J Endod 2012; 38(1): 101–4.
60. *Bürklein S, Tsotsis P, Schäfer* E. Incidence of dentinal defects after root canal preparation: reciprocating versus rotary instrumentation. J Endod 2013; 39(4): 501–4.
61. *Matus D, CantinM, Navarro P, Fonseca GM*. Evaluation of the cement/dentin thickness of the mesiobuccal root of maxillary first molars by optical microscopy in a Chilean sample. Biomed Res (India) 2017; 28(16): 6975–9.
62. *Degerness RA, Bowles WR*. Dimension, anatomy and morphology of the mesiobuccal root canal system in maxillary molars. J Endod 2010; 36(6): 985–9.
63. *Yoo YJ, Lee JK, Perinpanayagam H, Oh S, Gu Y, Chang SW,* et al. Morphological measurements of two separate mesiobuccal canals in maxillary first molars using micro-computed tomography. Clin Oral Invest 2020; 24(11): 3863–70.
64. *Mc Hugh ML*. Interrater reliability: the kappa statistic. Biochem Med (Zagreb) 2012; 22(3): 276–82.

Received on May 17, 2021
Revised on June 16, 2021
Accepted on July 14, 2021
Online First July 2021