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Micro-computed tomography analysis of root canal orifices in maxillary fused molars

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Purpose: This study outlines a two-dimensional analysis of root canal orifices in maxillary second molars showing different types of root fusion.

Methods: A total of 150 extracted fused maxillary second molar teeth with mature roots free of fractures, or deep caries extending to root dentine, were scanned on a micro-computed tomography (micro-CT) device (SkyScan 1172, Bruker-micro-CT, Kontich, Belgium) at 9 µm (pixel size), 100 kV, 100 µA. Specimens were classified according to the fusion type. In each specimen's axial slices of the pulp chamber floor, the area, perimeter, roundness, major diameter, and minor diameter values were measured. One-way analysis of variance test followed by post hoc Tukey test was performed to evaluate the area, perimeter, roundness, major diameter, minor diameter, and interorifice distances between different fusion types.

Results: The perimeter and area of the mesiobuccal 2 (MB2) canal orifice were statistically smaller than other orifices in all fusion types ($p< 0.05$). Major and minor diameter values of MB2 were also significantly smaller than that of mesiobuccal (MB) in fusion types 1 to 4 ($p< 0.05$), apart from type 6, in which major and minor diameters of MB, MB2, and distobuccal orifices were similar ($p> 0.05$). The largest area and perimeter values were measured in the palatal (P) canal orifice irrespective of the fusion type ($p< 0.05$).

Conclusion: The fusion type does not affect the area and minor diameter of the canal orifices. All morphological parameters examined were similar for MB and MB2 canal orifices regardless of the fusion type.

Keywords: Anatomy, endodontics, maxillary molar.

Introduction

Root fusion occurs by either cement deposition between roots or an anomaly in Hertwig's epithelial root sheath development and could affect the anatomy of permanent molars (1,2). More than two-thirds of the root length must be merged to be described as fused. Using micro-computed tomography (micro-CT) technology ex vivo, Zhang et al. (2) identified a prevalence of 42.25% of root fusions in the upper second molars in China; between those fused roots, 35.4% also had root canal merging (2). Root fusion classification, which was initially made in 1988 by Yang et al. (3), was later modified by Zhang et al. (2) and Martins et al. (4).

Partial or total root fusion of maxillary molars has been reported in different forms from the fusion of buccal

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roots to the complete fusion of all three roots presenting a conical-shaped single root (5). Fused roots have also shown a variety of canal configurations with the increased incidence of extra canals (6). The outcome of nonsurgical root canal treatment has been associated with the disinfection and obturation of all root canals, which require comprehensive knowledge about root canal anatomy and its possible variations. Failure to detect extra canals creates a higher probability for posttreatment apical periodontitis (7,8). The mesiobuccal (MB) root of maxillary molars has an oval cross-sectional shape with a larger diameter in buccolingual direction than mesiodistal direction and commonly presents two root canals, named MB1 and MB2, with a high incidence of fine anatomical structures including intercanal communications, loops, accessory canals, and apical ramifications (9). In fused teeth, the orifices of extra canals may be located at different levels, similar to non-fused teeth. Different fusion types create proximal or vestibular developmental grooves, which might decrease the dentin thickness around canals and promote periodontal inflammation and breakdown (10,11). This is clinically important since the orifice of an extra canal might be located under a dentin layer that requires removal of sound dentin, creating a danger zone area due to the significant decrease of dentin thickness because of grooves. Gates Glidden burs, ultrasonic tips, and orifice shaper NiTi instruments can be used to locate the canal orifices. When these devices are not used carefully, the risk of iatrogenic perforation increases. The knowledge of pulp chamber floor anatomy might help clinicians to avoid the risk of missing a canal.

Over the past 30 years, many methodologies have been described to study the internal and external configuration of maxillary molars using radiographic analysis (9), staining and cleaning, spiral computed tomographic imaging, and cone beam computed tomographic imaging. However, these methods are based on 2D images such as radiographic analysis (2). Cone beam computed tomography is a three-dimensional imaging method that has been used in dentistry for over 10 years. It allows viewing in slices and uses voxels instead of pixels. The spiral CT scanner provides enough image data to create 3D images with less scanning time and exposure compared with conventional CT scanners. Micro-CT technology is currently considered the most important and accurate research tool for studying the root canal system and amongst other applications, to understand the influence of its complex morphology on the different stages of endodontic treatment (11).

According to our research, no study has examined the dimensions of canal orifices of fused molars in the Turkish population. Thus, the purpose of this study was to determine whether the two-dimensional (2D) parameters (area, perimeter, major diameter, minor diameter, and roundness) of micro-CT images of the canal orifices in fused maxillary molar teeth differ in different fusion types (Fig. 1). The null hypothesis of the study was that there is no significant difference among the 2D parameters of canal orifices in different fusion types.

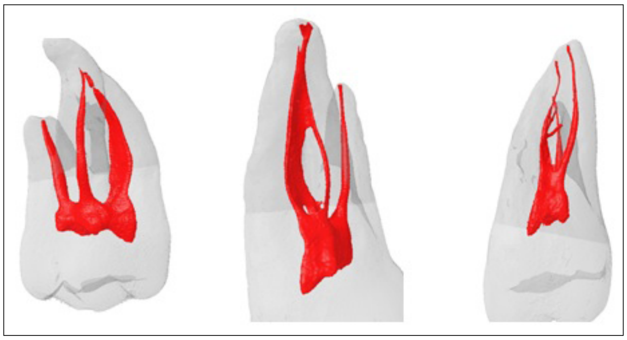

Fig. 1. Representative examples of fused maxillary molars.

Materials and Methods

The study protocol was reviewed by the local university ethical board with the approval number KAEK-2017-234. A total of 150 extracted maxillary second molar teeth, which have fused mature roots with a length more than 70% of the total root length, free of fractures, or deep caries extending to root dentine, were selected from the Turkish subpopulation and stored at 37°C with 100% humidity. The gender and age information of the patients were unavailable. The specimens were classified according to the fusion types as described by Zhang et al. (2) and modified by Martins et al. (4):

Type 1: MB root is fused with DB root

Type 2: MB root is fused with palatal (P) root

Type 3: DB root is fused with P root

Type 4: MB root is fused with DB root, and P root is fused with MB or DB root

Type 5: P root is fused with MB and DB roots

Type 6: MB, DB, and P roots are fused to form a cone-shaped root

Type 7: Single conical root

The teeth were scanned on a micro-CT device (SkyScan 1172, Bruker-microCT, Kontich, Belgium) at 9 μm (pixel size), 100 kV, 100 μA, 180° rotation range and 0.6° step, camera exposure time of 2200 ms and frame average of 1 with aluminum copper filters. Data reconstruction was performed by NRecon v.1.10.6. software (Bruker-microCT) with a beam hardening correction of 65%. CTAn v. 1. 17. 7. 2 (Bruker-microCT) and CTvol 2.3.2.0 (Bruker-microCT) software were used to create 3D models to visualize of root canal configurations. Following the examination of the 3D models, 10 specimens with an elongated pulp chamber up to the midroot level and 6 specimens with a single root canal were excluded. Then, in the axial slices of the pulp chamber floor of each specimen, area, perimeter, roundness, major diameter, and minor diameter values were measured using CTAn (v. 1.17.7.2, Bruker-microCT). Major diameter is the distance between the two furthest pixels at the mouth of the orifice, and minor diameter is the shortest line across the mouth of the canal perpendicular to the major diameter.

Statistical Analysis

One-way analysis of variance test followed by post hoc Tukey test was performed to evaluate the area, perimeter, roundness, major diameter, minor diameter, and inter-orifice distances among different fusion types using SPSS (Version 23.0, SPSS, Inc., Chicago, IL, USA) with 5% significance level.

Results

Tables 1 show that all 2D parameters of MB and MB2 canal orifices were similar among different fusion groups 1, 2, 3, 4, and 6 ($p > 0.05$). Type 5 and 7 fusion groups were omitted from the one-way analysis of variance analysis due to their small sample size.

The perimeter and area of the MB2 canal orifice were statistically smaller than other orifices in all fusion types ($p < 0.05$). Major and minor diameter values of MB2 were also significantly smaller than those of MB in fusion types 1 to 4 ($p < 0.05$), apart from type 6, in which major and minor diameters of MB, MB2, and DB orifices were similar ($p > 0.05$). The largest area and perimeter values were measured in P canal orifice irrespective of the fusion type ($p < 0.05$). The major diameter values of MB, MB2, and P orifices showed no significant difference according to the fusion types ($p > 0.05$), while DB canal orifice showed significantly greater major diameter values in fusion types 3, 1, and 4 than types 2 and 6 ($p < 0.05$).

In type 6 fusion (Table 1), no significant difference was found among the major diameter values of MB, MB2, and DB canal orifices ($p > 0.05$), and P orifice showed significantly greater values ($p < 0.05$). The same group also exhibited similar minor diameter values for all canal orifices ($p > 0.05$). Type 7 fusion group had only B and P root canals.

In type 1 fusion (Table 1), DB and P orifices showed significantly higher roundness values than those of MB and MB2 ($p < 0.05$). In type 3 fusion, P orifices had significantly greater roundness values compared with other canal orifices ($p < 0.05$). The roundness value of P orifice significantly decreased in fusion type 6 ($p < 0.05$) compared with types 1 and 2. In fusion types 2 and 4, roundness values of MB, MB2, DB, and P orifices showed similarity ($p > 0.05$).

Discussion

Root canal treatment aims to eliminate apical periodontitis by means of cleaning, shaping, disinfecting, and filling the entire root canal system. The most important cause of persistent endodontic infections is the residual microbial factors, thereby minimizing the microorganism number and load is a critical step during root canal treatment (12). The clinical implication of this goal necessitates the detection of all canal orifices at the beginning of root canal treatment. The MB canal system of maxillary molars has been reported to show multiple canals with a complex configuration, which challenges complete decontamination to eliminate inflammation in the periapical tissues of the involved tooth (8). The present study showed that the root canal orifice of MB2 is narrower than other canals. From a clinical point of view, MB2 could be more difficult to detect and negotiate compared with other canals. In addition, DB2 canal was also detected in a smaller number of specimens with major and minor diameter values similar to MB2. The narrow structure of MB2 and DB2 canals was not associated with a specific fusion type. In a recent study, the major and the minor diameters of MB1, MB2, and single MB were compared (13). Major and minor diameter ratio was determined as single MB > MB2 > MB1 by Shen and Gu (13). In our study, this ratio was found to be MB1 > MB2 in the fusion type 1, MB1 > MB2 in type 2, and MB1 > MB2 in type 3. In type 4 fusion, this ratio was equal for MB1 and MB2, while type 5 has a single MB. The ratio was MB2 > MB1 in type 6, and in type 7, there were no MB canals. Moreover, the minor and major diameter values of the second MB and DB canals were behind the threshold value to be successfully diagnosed with cone beam computed tomography with a conventional resolution in accordance with Shen and Gu (13).

Micro-CT is a unified imaging technology allowing non-destructive three-dimensional (3D) qualitative and quantitative analysis with high resolution (14). Techniques such as wax models, radiographic techniques, resin injection, use of contrast material, scanning electron microscopy, and transparency have been used to examine dental anatomy (15–17). Although these techniques allow us to understand the tooth structure, they cause irreversible changes in the tooth, they are insufficient to reveal fine anatomical structures, or various artifacts affect the image interpretation (15). Micro-CT can create three-dimensional (3D) models with the images taken from the cross-sections using X-rays without damaging the tooth. One

Table 1. Mean and standard deviations values for area (mm^2), perimeter (mm), roundness, major and minor diameter (mm) values of root canal orifices at pulp chamber level for each fusion type

	MB	MB2	DB	P	B*	DB2*
Type 1 fusion						
Area	0.60 ± 0.31^{a}	0.15 ± 0.12^{b}	0.49 ± 0.27^{ab}	1.23 ± 0.86^{c}	1.59 ± 0.49	–
Perimeter	3.70 ± 1.35^{a}	1.91 ± 0.82^{b}	3.21 ± 1.48^{a}	5.04 ± 2.27^{c}	6.02 ± 1.31	–
Roundness	0.42 ± 0.14^{a}	0.38 ± 0.17^{a}	0.56 ± 0.18^{b}	0.62 ± 0.17^{b}	0.46 ± 0.11	–
Major diameter	1.38 ± 0.53^{ac}	0.72 ± 0.32^{b}	1.08 ± 0.53^{ab}	1.58 ± 0.57^{c}	2.09 ± 0.46	–
Minor diameter	0.64 ± 0.16^{a}	0.31 ± 0.19^{b}	0.62 ± 0.18^{a}	1.05 ± 0.33^{c}	1.13 ± 0.21	–
	MB	**MB2**	**DB**	**P**	**B***	**DB2***
Type 2 fusion						
Area	0.46 ± 0.25^{a}	0.11 ± 0.10^{b}	0.28 ± 0.21^{ab}	1.16 ± 0.55^{c}	0.70	0.04
Perimeter	3.34 ± 1.43^{a}	1.69 ± 1.18^{a}	2.28 ± 1.01^{a}	6.04 ± 3.45^{b}	3.35	0.91
Roundness	0.44 ± 0.19a^{b}	0.39 ± 0.19^{b}	0.54 ± 0.13^{ab}	0.55 ± 0.16^{c}	0.70	0.62
Major diameter	1.23 ± 0.56^{a}	0.63 ± 0.41^{b}	0.77 ± 0.33^{b}	1.67 ± 0.73^{c}	1.12	0.31
Minor diameter	0.55 ± 0.12^{a}	0.25 ± 0.16^{b}	0.46 ± 0.18^{a}	1.01 ± 0.28^{c}	0.80	0.21
	MB	**MB2**	**DB**	**P**	**B***	**DB2***
Type 3 fusion						
Area	0.43 ± 0.17^{a}	0.10 ± 0.09^{b}	0.43 ± 0.25^{a}	1.12 ± 0.31^{c}	0.07	0.05 ± 0.06
Perimeter	3.72 ± 1.15^{a}	1.71 ± 1.00^{b}	3.81 ± 1.77^{a}	6.65 ± 2.62^{c}	1.35	0.93 ± 0.76
Roundness	0.33 ± 0.17^{a}	0.32 ± 0.16^{a}	0.34 ± 0.23^{a}	0.45 ± 0.16^{b}	0.40	0.48 ± 0.23
Major diameter	1.34 ± 0.43^{a}	0.67 ± 0.40^{b}	1.39 ± 0.63^{a}	1.85 ± 0.52^{a}	0.48	0.35 ± 0.30
Minor diameter	0.54 ± 0.15^{a}	0.23 ± 0.12^{b}	0.49 ± 0.25^{a}	1.01 ± 0.17^{c}	0.20	0.15 ± 0.08
	MB	**MB2**	**DB**	**P**	**B***	**DB2***
Type 4 fusion						
Area	0.42 ± 0.32^{a}	0.12 ± 0.21^{a}	0.36 ± 0.40^{a}	0.88 ± 0.40^{b}	0.73 ± 0.37	–
Perimeter	3.24 ± 1.65^{a}	1.48 ± 1.32^{a}	3.45 ± 3.02^{a}	5.92 ± 2.92^{c}	4.01 ± 1.50	–
Roundness	0.43 ± 0.20^{a}	0.44 ± 0.20^{a}	0.43 ± 0.20^{a}	0.44 ± 0.18^{a}	0.45 ± 0.21	–
Major diameter	1.14 ± 0.54^{a}	0.51 ± 0.46^{b}	1.05 ± 0.63^{a}	1.62 ± 0.47^{c}	1.52 ± 0.64	–
Minor diameter	0.54 ± 0.25^{a}	0.24 ± 0.21^{b}	0.51 ± 0.32^{a}	0.84 ± 0.28^{c}	0.70 ± 0.19	–
	MB	**MB2**	**DB**	**P**	**B**	**DB2**
Type 5 fusion*						
Area	0.64 ± 0.54	–	0.30 ± 0.23	0.67 ± 0.20	1.00	–
Perimeter	3.84 ± 2.11	–	2.96 ± 1.52	3.86 ± 0.46	5.85	–
Roundness	0.38 ± 0.14	–	0.32 ± 0.18	0.35 ± 0.10	0.30	–
Major diameter	1.42 ± 0.67	–	1.19 ± 0.65	1.53 ± 0.16	2.04	–
Minor diameter	0.60 ± 0.28	–	0.38 ± 0.16	0.62 ± 0.14	0.80	–
	MB	**MB2**	**DB**	**P**	**B***	**DB2***
Type 6 fusion						
Area	0.32 ± 0.18^{a}	0.16 ± 0.20^{a}	0.24 ± 0.22^{a}	0.89 ± 0.44^{b}	1.09 ± 0.81	1.00
Perimeter	2.72 ± 0.75^{a}	1.78 ± 1.14^{a}	2.38 ± 1.26^{a}	5.07 ± 1.75^{c}	5.16 ± 3.35	4.13
Roundness	0.39 ± 0.15^{a}	0.38 ± 0.58^{a}	0.43 ± 0.14^{a}	0.39 ± 0.13^{a}	0.47 ± 0.20	0.52
Major diameter	1.01 ± 0.22^{a}	0.64 ± 0.34^{a}	0.78 ± 0.31^{a}	1.60 ± 0.56^{b}	1.75 ± 0.94	1.55
Minor diameter	0.44 ± 0.18^{a}	0.33 ± 0.20^{a}	0.38 ± 0.20^{a}	0.72 ± 0.28^{a}	0.82 ± 0.31	0.97
	MB	**MB2**	**DB**	**P**	**B***	**DB2***
Type 7 fusion						
Area	–	–	–	0.75 ± 0.33	0.48 ± 0.37	–
Perimeter	–	–	–	4.06 ± 1.23	3.57 ± 2.41	–
Roundness	–	–	–	0.42 ± 0.17	0.46 ± 0.37	–
Major diameter	–	–	–	1.55 ± 0.68	1.42 ± 1.11	–
Minor diameter	–	–	–	0.69 ± 0.02	0.54 ± 0.02	–

*No statistical analysis was performed due to the small sample size. Different superscript letters within the same line indicate a statistically significant difference ($p < 0.05$). MB: Mesiobuccal; DB: Distobuccal; P: Palatal; MB2: second mesiobuccal; B: buccal; DB2: second distobuccal.

of the inherent limitations of ex vivo studies is ordinarily the narrow sample size collected from extracted molars, which must be considered when explicating the results. In the present study, collection and examination of 150 fused roots, which is less frequent than independent roots, were evaluated using micro-CT.

Root fusion often causes radicular groove formation on the root surface between the fused roots (17,18). The higher clinical incidence of periodontal disease was explicitly reported for type 1 fusion, which should be considered primarily from a periodontal aspect for the success of the treatment due to the presence of the deepest groove seen in the center of the buccal root surface. The concavity on the root surface might enable attachment loss (17). Another study reported endodontic–periodontal lesions related to 40% of the fused roots irrespective of the fusion type (18). Since the most common type of fusion was 1 in the evaluated subpopulation, when the presence of this root fusion is suspected, it is appropriate to consider the treatment from a multidisciplinary perspective.

The canal orifices can show different cross-sectional shapes according to the shape of canals. Root canal shaping and filling should be performed with more caution. In this study, roundness was different for each canal and fusion type. P canal has greater roundness values compared with other canals as expected and seen in other tooth groups. The roundness value for MB2 and DB2 was the lowest among all fusion types. In this study, DB2 root was found in types 2, 3, and 6. In type 6, the area, perimeter, roundness, major diameter, and minor diameter values were higher for DB2 than DB. DB2 canal was found in 70 of 150 sample teeth (46.6% of the fused second molars) in the Turkish population. Two canals in DB root were observed in some studies, and the prevalence of DB2 ranges from 0.6% to 4% in the Saudi population (16). This difference may occur because of the differences regarding sample size or population.

The type of fusion does not affect the area and minor diameter of the canal orifices. All parameters of the canal orifices in MB and MB2 canals were not affected by the fusion type. MB2 showed small values compared with MB canal orifices in all fusion types. In fusion types 1 and 2, the area and the major diameter of MB2 were similar to the DB canal orifice. In fusion types (6) where all canals merged, MB, MB2, and DB canal orifices showed similar morphological features. In light of these findings, the null hypothesis was rejected.

Conclusion

MB2 showed small values compared with MB canal orifice in all fusion types. In fusion types 1 and 2, the area and the major diameter of MB2 were similar to the DB canal orifice. In fusion types 6 and 7 where all canals merged, MB, MB2, and DB canal orifices showed similar morphological features.

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Ethical Approval: The study protocol was approved by the Ondokuz Mayıs University Faculty of Dentistry Clinical Research Ethics Commitee (date: 08.06.2017, protocol no: B.30.2.ODM.0.20.08/996).

Informed consent: Written informed consent was obtained from patients who participated in this study.

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