Evaluation of mesial root canal configuration of mandibular first molars using micro-computed tomography

Gülay Altan Şallı (ID)[1,]*, Edibe Egil (ID)[2]

[1]*Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Beykent University, Istanbul, Turkey*
[2]*Department of Pediatric Dentistry, Faculty of Dentistry, Istanbul Gelişim University, Istanbul, Turkey*

ABSTRACT

Purpose: The aim of this study was to evaluate the root canal morphology of mesial roots of mandibular first molars.

Materials and Methods: Forty extracted mandibular first molars were used in this study. The morphological examination of root canals was conducted in accordance with the Vertucci classification using micro-computed tomography (micro-CT). Any aberrant root canal configurations not included in the Vertucci classification were recorded, and their frequency was established using descriptive statistics. Intra-observer reliability was assessed using the Wilcoxon signed-rank test, while inter-observer reliability was assessed using the Cohen kappa test. Significance was evaluated at the $P < 0.05$ level.

Results: The mesial roots of mandibular first molars had canal configurations of type I (15%), type II (7.5%), type III (25%), type IV (10%), type V (2.5%), type VI (7.5%), and type VII (7.5%). The images showed 10 (25%) additional configuration types that were not included in the Vertucci classification. These types were 1-3-2-3, 1-2-3-2-3, 2-3-1, 2-3, 1-2-3-1, 2-1-2-3, 3-2-1, 1-2-3-1, 2-3-2-3, and 1-2-1-2-1. The intra-observer differences were not statistically significant ($P > 0.05$) and the kappa value for inter-observer agreement was found to be 0.957.

Conclusion: Frequent variations were detected in mesial roots of mandibular first molars. Clinicians should take into consideration the complex structure of the root canal morphology before commencing root canal treatment procedures to prevent iatrogenic complications. Micro-CT was a highly suitable method to provide accurate 3-dimensional visualizations of root canal morphology. *(Imaging Sci Dent 2021; 51: 383-8)*

KEY WORDS: Anatomy; Dental Pulp Cavity; X-Ray Microtomography; Dentition, Permanent

Introduction

It has been reported that the mandibular first molar is the tooth that most frequently receives endodontic treatment.[1,2] Although each particular tooth is thought to contain a certain number of roots and canals, previous studies have shown that variations in tooth morphology are common.[3] The number and classification of root canals can also differ according to ethnicity and sex, as well as among different populations and even within the same population.[4] Studies of different populations are therefore important to determine the full extent of this diversity.

Due to the high prevalence of curvatures and internal communications, mesial roots of mandibular molars have one of the most complicated internal anatomies.[5,6] The mandibular first molar usually has 2 roots: 1 distal and 1 mesial. The mesial root presents a number of anatomical challenges for dental clinicians, such as multiple canals, isthmuses, and apical deltas.[6,7] The distal root usually has a simple tubular Vertucci type I configuration.[8] The effect of undetected canals, such as middle mesial and lingual canals, on the outcomes of endodontic treatment has been reported in previous studies.[9,10] It is important that each step of root canal treatment, including shaping, cleaning, and filling,

should be meticulously performed. Therefore, in-depth knowledge of root canal anatomy and morphology is essential for achieving successful treatment.[4]

Various techniques, such as plastic resin injection, the clearing method, radiography, scanning electron microscopy, histology, conventional computed tomography (CT), cone-beam computed tomography (CBCT), and micro-CT, have been used to determine the internal anatomy of mandibular molar teeth. The clearing method renders the tooth transparent by injecting liquid material into the tooth to cause demineralization, and it was widely considered to be the most suitable method for examining the morphology of the root canal system. The main disadvantage of this system is that it causes irreversible changes in the dental tissue.[5,11] With the improvement of 3-dimensional (3D) digital systems, CBCT has proven to be a valuable method for examining the morphology of the root canal system. Among these techniques, micro-CT imaging is the most promising method, as it provides accurate high-resolution images, and moreover, it is preferred for determining root canal morphology because it is a non-invasive method for obtaining detailed 3D imaging features.[5,12,13]

The root canal morphology of mandibular first permanent teeth has been examined in previous studies. Ordinola-Zapata et al.[5] evaluated 32 mandibular first molar mesial canals using the dye penetration and transparency techniques and micro-CT imaging. They then categorized the obtained images according to the Vertucci classification. Kim et al.[14] examined the root canal morphology of 31 extracted mandibular first molar teeth, and compared the dye penetration and transparency techniques with the micro-CT technique. They found the micro-CT method was successful in viewing channel configurations. Villa-Bôas et al.[6] examined the root anatomy of 60 first and second mandibular molars by micro-CT, and reported that there were a large number of variations in the apical root formation of mandibular molars.

The classifications proposed by Weine et al. and Vertucci et al. are the most widely used systems in the literature. Weine et al.[15] were the first to categorize root canal configurations within a single root into 4 basic types. Vertucci further elaborated the Weine classification to classify root canal systems into 8 types.[11,16] Therefore, the present study used the classification developed by Vertucci et al. However, examples of canals that do not fit these canal classifications have been identified by various researchers.[8,17,18]

Several studies have examined the mesial root morphology of mandibular molars in different populations.[8,18,19] The study of root and canal anatomy is of clinical and anthro-pological importance, and racial and/or regional tendencies contribute to anatomical variations.[19,20] Walker[21] reported that the presence of a second canal in the distal root of the mandibular first molar is more common in American Indian and Asian populations than in European or African ones. This descriptive study was designed to identify the mesial root canal morphology of mandibular first molars using micro-CT. To the best of the authors' knowledge, this issue has not previously been investigated according to the Vertucci classification specifically within the Turkish population.

Materials and Methods

Mandibular permanent first molars (n = 40) were used in this study. These teeth, which had been extracted for reasons unrelated to the present study (dental caries, prosthodontic or orthodontic treatments, periodontal causes, etc.), were collected from 5 different dental clinics in Istanbul. Patients' age and sex were not recorded. The inclusion criteria for this study were that the apex of the teeth should be closed, there should be no root resorption (or resorption should not exceed the apical third), and there should be no root fractures. The exclusion criteria from this study included external root resorption, incomplete apex development, and the presence of root fractures. The study was approved by Biruni University's Ethics Committee. The study protocol reference is 2019/25-16.

After the selected teeth (n = 40) were cleaned under tap water, they were kept in 3% sodium hypochlorite solution for 1 hour. The teeth were then mechanically cleaned with an ultrasonic scaler and a curette to remove any organic residue or calculus from the surface. They were then stored in distilled water at 4°C until use. Each tooth was gently dried, mounted on special apparatus, and scanned using a micro-CT scanner (SkyScan 1172 X-ray micro-CT; SkyScan, Antwerp, Belgium) employing 97 kV at 102 μA and a scan time of 30 minutes. Transmission X-ray images were recorded in 0.5° rotational steps for 360° of rotation around the vertical axis, using a 0.5-mm-thick aluminum filter. The raw data from each sample were reconstructed (NRecon/InstaRecon v.1172 SkyScan micro-CT reconstruction engine) and images were obtained. The cross-sectional images were transferred to a 3D visualization software package (CTan for 2D visualization and 2D/3D analysis, CTvol for realistic 3D visualization, and DataViewer v.1172 SkyScan micro-CT software for 3D analysis on sagittal, coronal, and axial slices). The images were then assessed on a monitor screen (21.5-inch full HD LED, 1920 × 1080 pixels, Casper 215 CSR model, Casper Computer Systems Inc., Istanbul, Turkey).

The morphology of the root canal was evaluated and classified into 8 types according to the Vertucci classification: type I (1): a single canal extends from the pulp chamber to the apex; type II (2-1): 2 separate canals leave the pulp chamber and join short of the apex to form 1 canal; type III (1-2-1): 1 canal leaves the pulp chamber, divides into 2 within the root, and then merges to exit as 1 canal; type IV (2): 2 separate and distinct canals extend from the pulp chamber to the apex; type V (1-2): 1 canal leaves the pulp chamber and divides short of the apex into 2 separate and distinct canals with separate apical foramina; type VI (2-1-2): 2 separate canals leave the pulp chamber, merge into the body of the root, and redivide short of the apex to exit as 2 distinct canals; type VII (1-2-1-2): 1 canal leaves the pulp chamber, divides and then rejoins within the body of the root, and finally redivides into 2 distinct canals short of the apex; and type VIII (3): 3 separate and distinct canals extend from the pulp chamber to the apex.[11]

Any abnormal root canal configurations that did not fit the Vertucci classification were identified. Data were recorded within a table created with Microsoft Excel 2016 (Microsoft Corp., Redmond, WA, USA). Evaluations were made using descriptive statistics to establish the frequency. Frequency analysis was then performed using SPSS version 21.0 (IBM Corp., Armonk, NY, USA). Two observers independently evaluated the radiological images in a darkened, quiet room. Inter-observer concordance reliability was assessed using the Cohen kappa test, and intra-observer reliability using the Wilcoxon signed-rank test. Each observer analyzed the images of the first 10 teeth (25% of the sample), and then the same observers, blind to the results of the first assessment, repeated the assessment 4 weeks later.

Results

The sample size for the study was 40 teeth. The results aligned with the Vertucci classification in 75% (30/40) of the roots. The mesial roots exhibited canal configurations of type I (6, 15%), type II (3, 7.5%), type III (10, 25%), type IV (4, 10%), type V (1, 2.5%), type VI (3, 7.5%), and type VII (3, 7.5%) (Table 1). Representative examples are shown in Figure 1.

The examined images also revealed 10 configurations (25%) that did not fit into the Vertucci classification. These were types 2-3, 2-3-1, 3-2-1, 1-3-2-3, 1-2-3-1, 2-1-2-3, 1-2-3-1, 2-3-2-3, 1-2-3-2-3, 1-2-1-2-1). Among these, 8 configurations (3-2-1, 1-3-2-3, 1-2-3-1, 2-1-2-3, 1-2-3-1, 2-3-2-3, 1-2-3-2-3, 1-2-1-2-1) have not been previously reported in academic studies. Representative examples are shown in Figure 2.

The differences in intra-observer agreement were not statistically significant ($P > 0.05$). The inter-observer agreement value was 0.957, showing a high level of both intra- and inter-observer reliability.

Discussion

Table 1. Distribution of canal types according to the Vertucci classification among mesial roots of mandibular first molars

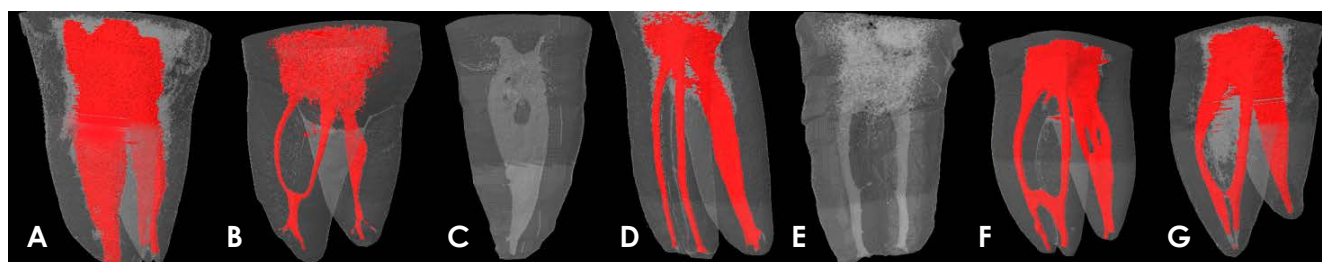| Canal configuration	Canal type	Number (%)
1	Type 1	6 (15)
21	Type 2	3 (7.5)
121	Type 3	10 (25)
	Total with 1 canal at apex	19
2	Type 4	4 (10)
12	Type 5	1 (2.5)
212	Type 6	3 (7.5)
1212	Type 7	3 (7.5)
	Total with 2 canals at the apex	11
3	Type 8	0
Others		10 (25)

Fig. 1. Representative examples of root canal configuration types that fit the Vertucci classification, based on data obtained using micro-computed tomography. A. Type I (1). B. Type II (2-1). C. Type III (1-2-1). D. Type IV (2). E. Type V (1-2). F. Type VI (2-1-2). G. Type VII (1-2-1-2).
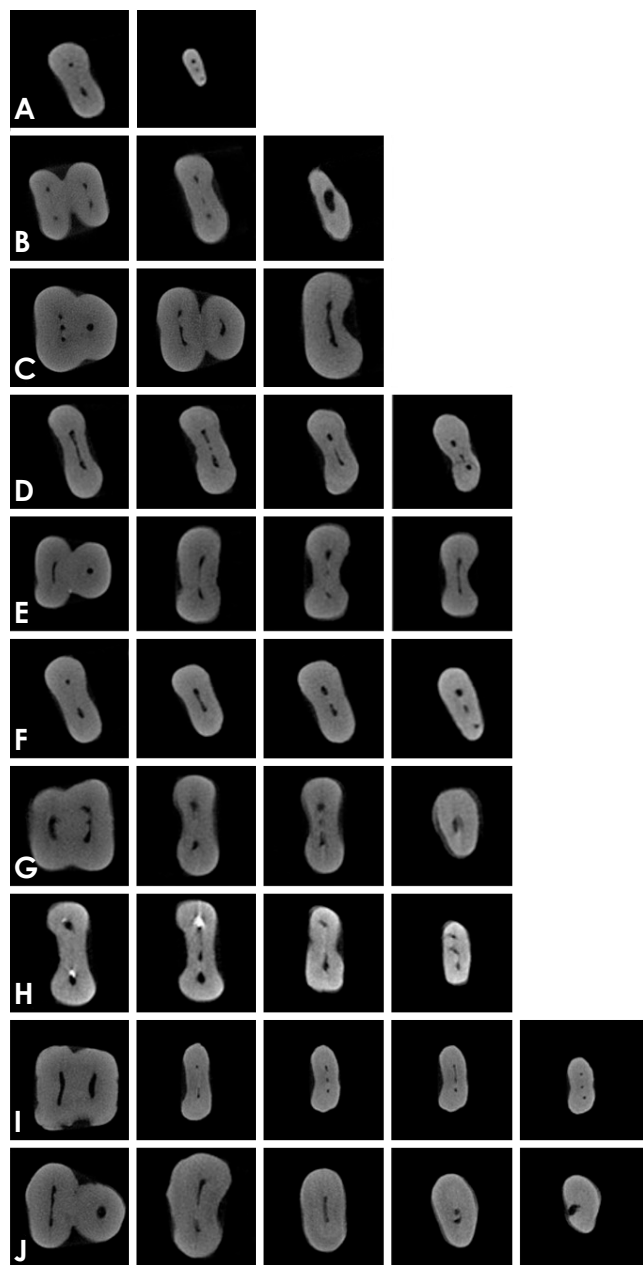
Fig. 2. Representative examples of root canal configuration types that do not fit the Vertucci classification, based on data obtained from DataViewer on axial slices. A. Type (2-3). B. Type (2-3-1). C. Type (3-2-1). D. Type (1-3-2-3). E. Type (1-2-3-1). F. Type (2-1-2-3). G. Type (1-2-3-1). H. Type (2-3-2-3). I. Type (1-2-3-2-3). J. Type (1-2-1-2-1).

Many researchers have examined the root canal morphology of human permanent teeth using a number of methods, such as analyzing transparencies of previously stained samples, macroscopic sections, and radiographs of extracted teeth.[22] The development of X-ray micro-CT imaging has gained increasing importance in the study of dental tissues.[23] It has been used as a tool for the 3D reconstruction of internal and external tooth morphology due to its high-resolution capability, which is perfectly suited for root canal studies. Moreover, micro-CT provides quantitative and qualitative assessment of the root canal system under *in vitro* conditions.[24]

Ordinola-Zapata et al.[5] examined the mesial roots of 32 mandibular first molars with multiple methods that included micro-CT. They stated that the evaluation method and the anatomy type are both important for accurately defining the canal configuration in the mesial root. They also concluded that the micro-CT method had the highest level of accuracy. The present study used micro-CT to identify different canal configurations of mesial roots of mandibular molars.

Weine[25] reported a mandibular first molar with 3 canals in the mesial root. Vertucci[11] reported that the type IV (2) canal was observed in 43% of mesial roots in their study, while the type II (2-1) canal forms were observed in 28%. Berna and Badanelli[26] reported 2 cases in which the first molars had 3 canals in the mesial and distal roots.[26] Calıskan et al.[27] encountered type II (2-1) morphology in 37% of mesial roots and type IV in 44%. Gulabivala et al.[8] reported that the most frequent canal configurations were type IV (n = 53; 38.1%) and type II (n = 40; 28.8%) in their study. Sert et al.[28] reported that the most common findings were type II (1-2) (44%) and type IV (2) (43%). Pablo et al.[29] stated that their most commonly observed canal types were type IV and type II. Harris et al.[30] observed highly variable canal morphology in the mesial root, with the most common configuration being type V (22.7%). Gambarini et al.[31] also assessed the canal configurations of mandibular first molar mesial roots and reported that 59% of cases were type IV, while 41% were type II. Marceliano-Alves et al.[32] recorded the highest frequency as belonging to type IV (n = 48; 46.2%), followed by type II (n = 17; 16.3%). Type VIII was detected in 7.7% (n = 8) of the samples.

In contrast to those previous studies, the most frequent canal configuration observed in this research was type III, followed by type I. This shows that different results may be obtained when analyzing canal configurations across different studies. Factors such as sex, ethnicity, and population type may play a role in forming the basis of these differences. It has also been stated that variations in the root canal morphology of mandibular molars are racially and genetically determined.[18]

In other studies, several canal configurations that do not fit within the Vertucci classification have been reported. These are type IX (1-3), type X (1-2-3-2), type XI (1-2-3-4), type XII (2-3-1), type XIII (1-2-1-3), type (4-2), type (3-2), type (1-3-1), type (2-3), type (2-1-2-1), type (3-1), type (4),

type (4-1), and type (5-4).[8,17,33] In this study, 2 types were observed to fit within these additional configurations: type (2-3) and type XII (2-3-1). In addition, 8 new configurations were found (3-2-1, 1-3-2-3, 1-2-3-1, 2-1-2-3, 1-2-3-1, 2-3-2-3, 1-2-3-2-3, 1-2-1-2-1), and this study marks the first time they were observed in mesial roots of mandibular first molars.

The canal configuration type plays an important role in predicting endodontic treatment success. It is envisaged that teeth with simple tubular configurations (types I, IV, and VIII) will be shaped and filled successfully; however, debridement and shaping of teeth with branched canal configurations (types III, VI, and VII) can prove difficult.[8] Techniques can be divided into 2 categories: *in vivo* (performed directly in patients) and *ex vivo* (performed using extracted teeth).[31] Although the current study shows that micro-CT is useful for the examination of root canal morphology, it should only be used when it is impossible to assess the root canal system accurately by conventional techniques, such as periapical radiography. The reason for this is that micro-CT is recommended for *in vitro* investigations of the internal and external morphology of dental structures, not in living persons. When there are abnormal findings, CBCT may be necessary for *in vivo* imaging.[18]

The present study has some limitations. The sample size was relatively small, and further studies are needed on larger cohorts regarding this issue.

In the current study, a high rate of variation was detected in the morphology of mesial roots of mandibular first molars. The high prevalence of additional configurations demonstrates the inherent complexity of the mesial root canal anatomy. Clinicians should take this complexity into consideration before commencing root canal treatment procedures to prevent the incidence of iatrogenic complications related to shaping and cleaning procedures. Furthermore, micro-CT is a highly suitable method to obtain 3D imagery that accurately reveals the intricacy of root canal morphology.

Conflicts of Interest: None

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