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ORIGINAL ARTICLE

A micro-computed tomography study of canal configuration of multiple-canalled mesiobuccal root of maxillary first molar

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Abstract
Objectives Detailed information of complex anatomical configuration of mesiobuccal (MB) root is essential for successful endodontic treatment in maxillary first molars. The aims of this study were to investigate the configuration types present in multiple-canalled MB roots of maxillary first molars using micro-computed tomography (μCT) and to evaluate whether further modification to current configuration classifications are needed for in-depth morphology study of MB root canal system.
Materials and methods One hundred and fifty-four extracted human maxillary first molar MB roots were scanned by μCT (Skyscan) and their canals were reconstructed by 3D modeling software. Root canal configurations were categorized according to the classifications proposed by Weine and Vertucci. Canal configurations that did not fit into both classifications were categorized as non-classifiable.
Results One hundred and thirteen (73.4 %) MB roots had multiple canals. The most predominant canal configuration was Weine type III (two orifices and two foramens). Thirty-three (29.2 %) and 20 (17.7 %) MB roots had non-classifiable configuration types that could not be classified by the Weine and Vertucci classification, respectively. Three configurations (types 1–3, 2–3–2–3–2, and 2–3–4–3–2) were first reported in maxillary first molar MB roots.
Conclusions The present μCT study provided an in-depth analysis of canal configurations of the MB roots of maxillary first molar and suggests that additional modification of current configuration classifications may be needed to more accurately reflect the morphology configurations of MB roots.
Clinical relevance Clinicians should consider the complex canal configurations of the maxillary first molar MB roots during surgical or nonsurgical endodontic procedures.

Keywords Canal configuration · Mesiobuccal root · Micro-computed tomography · Non-classifiable · Vertucci classification · Weine classification

Introduction

The main objective of root canal treatment is thorough shaping and cleaning of the entire root canal system and its complete obturation with inert filling materials [1]. Therefore, knowledge of the canal morphology and its frequent

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variations is a basic requirement for endodontic success [1–3]. Root canal morphology and configurations have been widely studied and classified by various researchers, especially in the mesiobuccal (MB) roots of the maxillary first molar teeth, because of the high prevalence of additional canals and their complex configurations [1, 3–11]. However, earlier morphological study methods, such as sectioning and clearing [1, 3, 5–8], were destructive or produced artifacts and distortion of the internal anatomy of the specimens. Thus, these methods could provide limited information about the intricate anatomy and canal configurations of MB root canal system. Moreover, there are concerns that the classic configuration classifications suggested by Weine [3] and Vertucci [1] need additional configurations for fully encompassing the complexity of MB root canal [5–8].

Recently, technological advances have emerged that can facilitate the assessment of the internal anatomical variations of root canal systems. Among these, the advent of micro-computed tomography (μCT) coupled with mathematical modeling has allowed a detailed 3D assessment of the internal and external root canal anatomy [12–19]. The resolution of recent μCT was reported to be 15–25 μm which is quite smaller than that of conventional CT (1–2 mm) [20]. Furthermore, the results of recent μCT studies suggested that 3D modeling analysis made it possible to study the anatomy more accurately while overcoming the shortcomings of earlier morphological studies [14, 18]. Recently, two μCT studies reported a high incidence of non-classifiable configurations that could not be categorized using the Vertucci configuration classifications for maxillary first molar MB roots [17, 19]. This suggests that the maxillary first molar MB root has a complex canal anatomy and that the current configuration classifications for maxillary molars in the literature do not fully reflect this complexity. Therefore, the aims of this study were to investigate the canal configuration types in multiple-canalled MB roots of maxillary first molars using μCT and to evaluate whether further modification for current configuration classifications are needed for in-depth morphology study of MB root canal system.

Materials and methods

Sample preparation

This study was carried out under the approval of the Institutional Review Board of Seoul National University Dental Hospital, Seoul, Korea. One hundred fifty-four human maxillary first molar teeth with fully formed apices and intact crowns without root fracture or endodontic treatment were collected from patients (aged 27–68 years). These teeth were extracted for periodontal disease and due to prosthodontic reasons. Root surfaces were cleaned of calculi and soft tissues with an ultrasonic scaler and hand curettes. Thereafter, the teeth were soaked in 3.5 % sodium hypochlorite for one hour and stored in a 0.5 % sodium azide solution at 4 °C until use.

Micro CT scanning and 3D reconstruction

The teeth were scanned by μCT (SkyScan 1172, SkyScan, Aartselaar, Belgium) using 100 kV (tube voltage), 100 μA (tube current), an 0.5-mm-thick aluminum filter, and 0.5° rotation steps for 180° of rotation. Acquired images had a pixel size of 15.9 × 15.9 μm. The distance between each image was 15.9 μm. From the volume of these images, 3D models were rendered for inspection of the canal systems using OnDemand3D software (Cybermed, Seoul, Republic of Korea). To enhance visualization of the fine root canal structure, segmented volumes of canal structure were represented by an opaque red color and the external morphology of the root was rendered transparent.

Observations of MB root canal configuration

One endodontist analyzed and classified the 3D reconstructed images once a week for 3 weeks to minimize the bias by observer. Mesiobuccal roots of maxillary first molars with more than two canals were selected from the μCT images of 154 teeth. Root canal configurations of multiple-canalled MB roots were categorized according to the classifications proposed by Weine [3] and Vertucci [1] as follows;

- Vertucci type I (Weine type II). Two separate canals leave the pulp chamber and join short of the apex to form one canal.
- Vertucci type II One canal leaves the pulp chamber, divides into two within the root, and then merges to exit as one canal.
- Vertucci type III (Weine type III). Two separate and distinct canals extend from the pulp chamber to the apex.
- Vertucci type IV (Weine type IV). One canal leaves the pulp chamber and divides short of the apex into two separate and distinct canals with separate apical foramina.
- Vertucci type V Two separate canals leave the pulp chamber, merge in the body of the root, and redivide short of the apex and exit as two distinct canals.
- Vertucci type VI One canal leaves the pulp chamber, divides and then rejoins within the body of the root, and finally redivides into two distinct canals short of the apex.
- Vertucci type VII Three separate and distinct canals extend from the pulp chamber to the apex.

Canal configurations that did not fit into two classifications were categorized as non-classifiable. The use of both classification systems is based on the fact that Weine is the

Table 1 The types and incidence of canal configurations categorized by Weine classification in 113 maxillary first molar MB roots with multiple canals

Types of canal configurations	Type II (2–1)	Type III (2)	Type IV (1–2)	NC	Total
No. of teeth	26	37	17	33	113
%	23.0	32.8	15.0	29.2	100

NC non-classifiable configuration types that were not categorized by the Weine classification [3]

more frequently used classic classification, but Vertucci is more detailed. In our study, for the exact classification of canal configuration, the description of a main canal, accessory (lateral) canal, and intercanal communication(s) was based on the terminology defined by Vertucci [2].

Results

Among the 113 (73.4 %) MB roots with additional canals, 94 MB roots had two canals and 19 MB roots had three or more canals. A variety of canal configuration types were found in the multiple-canalled MB roots. The types and incidence of configurations found in the 113 MB roots by Weine and Vertucci classification are shown in Tables 1 and 2, respectively. When they were classified using Weine classification, the most prevalent configuration was Weine's type III (32.8 %), followed by type II (23.0 %), type IV (15.0 %). Thirty-three (29.2 %) MB roots were non-classifiable by Weine classification. When classified using Vertucci classification, the most common configuration was Vertucci's type II (23.0 %) followed by type IV (19.5 %), type VI (13.3 %), type III (10.6 %), type V (9.7 %), type VII (5.3 %), and type VIII (0.9 %). 3D reconstructed images of configuration types, according to the classifications proposed by Weine [3] and Vertucci [1], found in the 113 MB roots are illustrated in Fig. 1. Twenty (17.7 %) MB roots had 12 non-classifiable configuration types that were not included by Vertucci classification. These were types 1–2–1–2–1, 1–2–1–3, 1–3, 2–1–2–1, 2–1–2–1–2, 2–1–3, 2–3, 2–3–2–3–2, 2–3–4–3–2, 3–2, 3–2–1, and 3–2–1–2–1 (Fig. 2). Among these, three configurations (types 1–3, 2–3–2–3–2, and 2–3–4–3–2) were first reported in maxillary first molar MB roots. The root canals with non-classifiable configurations merged and then divided in mid-root, or vice versa, leading to the complex canal configurations.

Discussion

Eder et al. [21] reported that CT could describe the exact canal configuration, verify information identical to histology, and thus serve as the "gold standard" in vitro morphology study. The present μCT study also provided in-depth analysis of canal configuration of the maxillary first molar MB roots and suggests that additional modification of the classic configuration classifications may be needed to more accurate description of the morphology configurations in MB roots. Weine [3] divided the position of one or two canals within one root into four categories and Vertucci [1] described a classification encompassing eight different types in permanent teeth. Both configuration classifications have been widely used as classic standards for morphology study. After that, Ng et al. [5] modified the Vertucci classification by adding seven additional configuration types for in-depth morphology study of maxillary molar teeth and found three additional configurations (types 2–1–2–1, 3–2, and 2–3) in Burmese maxillary first molars. Alavi et al. [8] also reported one configuration (type 1–3–1) that was not classifiable by the Vertucci classification in Thai maxillary first molars. In their two morphology studies that used clearing technique in Turkish maxillary first molars, Sert and Bayirli [6] and Sert et al. [7] reported two (types 3–2–1 and 2–3–2–1–2) and three (types 1–2–3–2, 2–3, and 2–1–2–1) new configurations that were not included in the Vertucci classification, respectively. Recently, Verma and Love [17] and Gu et al. [19] in their μCT studies reported six and nine new configurations, respectively, that were not classifiable by the Vertucci classification. The present μCT study also found 12 non-classifiable configuration types that were not included in the Vertucci classification. Moreover, among these, three configurations (types 1–3, 2–3–2–3–2, and 2–3–4–3–2) have never been reported for maxillary first molar MB roots. These suggest that any of current MB canal configuration classification and its modified version cannot fully reflect the anatomical complexity of the maxillary first molar MB roots. Furthermore, the root canals with non-classifiable configurations branched, divided, and rejoined again in mid-root, or vice versa. These anatomical complexities can make mechanical instrumentation in these areas unfeasible. Therefore, dentists

Table 2 The types and incidence of canal configurations classified by Vertucci classification in 113 maxillary first molar MB roots with multiple canals

Types of canal configurations	Type II (2–1)	Type III (1–2–1)	Type IV (2)	Type V (1–2)	Type VI (2–1–2)	Type VII (1–2–1–2)	Type VIII (3)	NC	Total
No. of teeth	26	12	22	11	15	6	1	20	113
%	23.0	10.6	19.5	9.7	13.3	5.3	0.9	17.7	100

NC non-classifiable configuration types that were not categorized by the Vertucci classification [1]

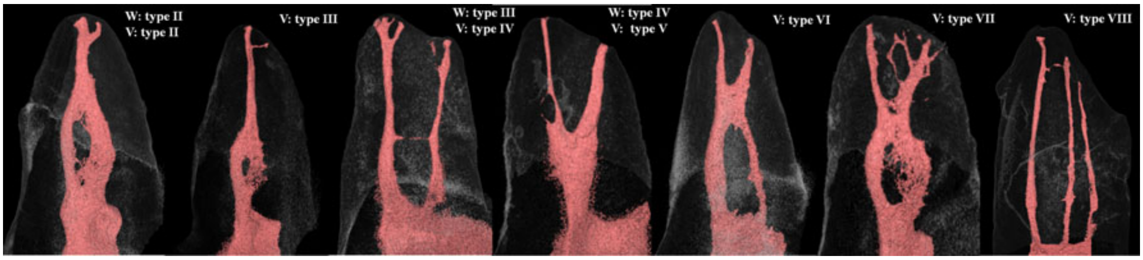

Fig. 1 3D reconstructed images of seven configuration types identified according to the Weine and Vertucci classification in the 113 MB roots with multiple canals (*W*: Weine classification, *V*: Vertucci classification)

should concentrate on efficient delivery and activation of irrigants as well as intracanal medication to achieve proper disinfection. Peters et al. [22] reported that variations in canal geometry before shaping and cleaning procedures had more influence on the changes that occur during preparation than the instrumentation techniques themselves. In clinical situations, negotiation of the additional MB canal(s) is often difficult due to a dentine shelf that covers its orifices and the MB inclination of its orifices on the pulpal floor [2]. Moreover, there have been reports of the existence of pronounced curvatures and a high incidence of calcified segments within the coronal portion of MB2 canals [8, 12]. Therefore, careless dentin removal using high-speed burs to locate the canals may lead to furcal wall perforation of this root as a concavity exists on its distal surface. Instead, most of these obstructions can be eliminated by 'troughing or countersinking' with ultrasonic tips mesially and apically along the mesiobuccal–palatal groove [2, 8]. This difficulty and risk of negotiating MB canals can frustrate many clinicians in treating maxillary first molar teeth. Failure to access, debride, and disinfect the complex MB root canals might have a direct effect on the treatment outcome [23].

Regarding the types of canal configurations in multiple-canalled MB roots, the present results showed that the most common canal configuration had two orifices and two foramens (Weine type III, Vertucci types IV + VI). The high prevalence of two orifices and two foramens, which is a typical Mongoloid trait [24], is in agreement with the findings of earlier studies in East and South Asian, Indian, and Mexican populations [5, 8, 9, 12, 19, 24–26]. These are in contrast to the results identified in the Caucasian population [1, 16], where the most prevalent canal morphology had two orifices and one foramen (Weine type II, Vertucci type II). These variations in canal morphologies might be attributed to multiple factors, such as the study design (clinical or laboratory), methods of canal identification, racial divergence, age, number of the subject or teeth, or gender [1, 3–10, 16, 19, 24–27].

Regarding the incidence of additional canals in maxillary first molar MB root, Cleghorn et al. [11] reported that the incidence (60.5 %) in the laboratory studies was higher compared to the clinical studies (54.7 %). The present in vitro μCT results using 3D analysis revealed a high incidence (73.4 %) and the incidence was within the ranges (71.7, 80, and 76.2 %) reported in three recent μCT studies

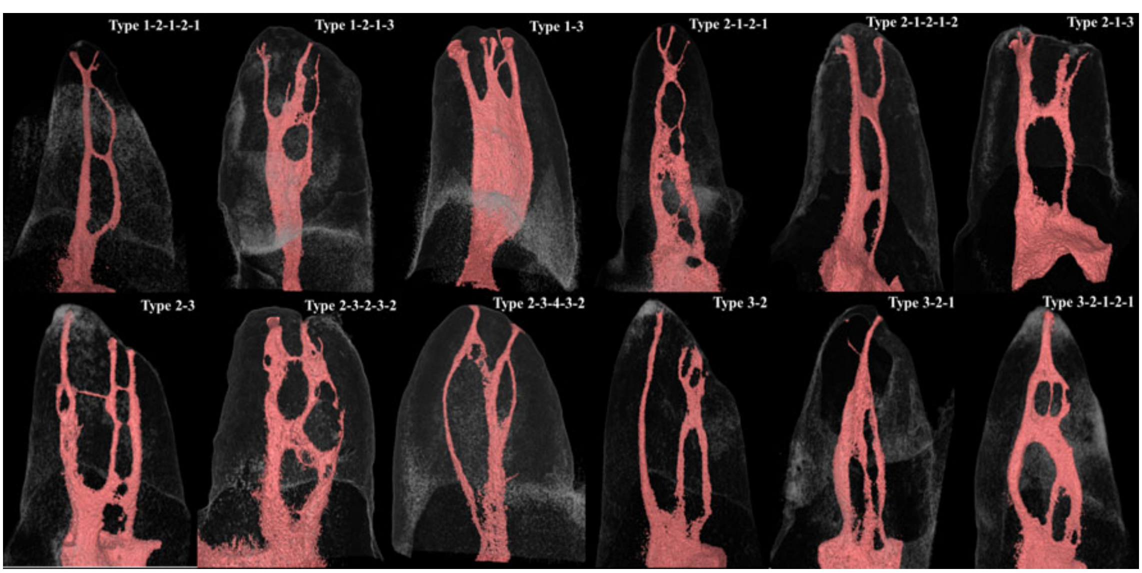

Fig. 2 3D reconstructed images of 12 non-classifiable configuration types that are not included in the Vertucci classification in this study

using 3D analysis [12, 16, 19]. Recent clinical study has reported that age has a positive effect on the incidence and configurations of an MB2 canal in maxillary molar MB roots [26], especially in those patients below 40 years of age. Hess [28] has reported that a broad canal diverges into two canals as a patient grows older because of the deposition of dentin between the canal walls at the narrowest points. Thomas et al. [27] reported that MB canals of maxillary molars have wide variations in canal morphology owing to continuous deposition of dentin in mesiodistal and buccolingual directions. In this respect, the incidence or configurations of additional canals in MB root may be affected by aging process because older teeth have more calcified canals, and the diameter(s) of the additional canals are smaller than the diameter of the MB1 canal [29]. Therefore, clinicians must try to find, debride, and fill the additional canal(s) in treating MB roots of maxillary first molars in old patients with the help of surgical operating microscope [10] or additional diagnostic method such as cone beam CT [24, 26].

The present μCT study has accurately portrayed the complex anatomic configurations of the MB roots of maxillary first molar. Although this technique is time consuming, the 3D reconstructions with high resolution and accuracy are widely applied in experimental endodontology [15, 22, 30–35], which may someday aid in our provision of endodontic therapy.

In conclusion, the present results clearly demonstrate that μCT is a viable tool for in-depth analysis of canal configurations of the MB roots of maxillary first molar and suggest that additional classifications may be needed to more accurately reflect morphology configurations in the MB roots. These complex configurations in the MB roots of maxillary first molar should be considered during surgical or nonsurgical endodontic procedures.

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