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Three-dimensional Analysis of Mesiobuccal Root Canal of Japanese Maxillary First Molar Using Micro-CT

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Abstract

The objective of this study was to three-dimensionally observe the morphological characteristics of mesiobuccal root canals of Japanese maxillary first molars using microcomputed tomography (Micro-CT) and classify root canal variations. This study used 90 maxillary first molars. Three-dimensional reconstruction was performed using data obtained by Micro-CT, and cross-sections of the root canals were observed. Moreover, the root canal morphology was classified by the configuration and root canal diameter, and was evaluated for occurrence using the classification by Weine et al. (1969) as a reference. Overall, single root canals were observed in 44.4%, incomplete separation root canals in 22.3%, and completely separate root canals (upper and lower separation root canals) in 33.3%. Mesiobuccal root canals often had intricate configurations, and accessory root canals (lateral canals and apical ramifications) were observed in most of the mesiobuccal root canals (76.7%), irrespective of whether there were ramifications of the main root canals. While there were no marked differences in the incidence of root canal ramifications between this study and earlier reports, the incidence of accessory root canals was higher in this study. This result may be explained by the far more superior visualization ability of Micro-CT than conventional methods, which allowed the detection of microscopic apical ramifications previously difficult to observe.

Key words: Micro-CT—Maxillary first molar—Mesiobuccal root canal—Main root canal separation—Apical ramification

Introduction

There is general agreement that root canal treatment of maxillary first molars is difficult. In particular, the mesiobuccal root often has a separate root canal with a root canal orifice or root canal ramifications. For this reason, various methods have been used to determine the rate of root canal ramifications, however, all of these ana-
tomical or clinical methods have depended on classification based on unique criteria, and there are few reports involving numerical criteria.\(^2,16,21,23\)

We imaged human teeth with microcomputed tomography (Micro-CT) and observed slices of root canals of human maxillary first molars using three-dimensional (3-D) reconstructions produced in a nondestructive manner using 3-D reconstruction software. Based on the results, the rate of root canal classifications was calculated according to newly established criteria using the root canal classification by Weine \(et\ al.\)\(^{25}\) as a reference.

**Materials and Methods**

We used 90 Japanese maxillary first molars stored at the Department of Anatomy, Tokyo Dental College, which had few parenchymatous defects, such as caries. The samples were imaged using Micro-CT (HMX225-ACTIS 4, TESCO, Inc.). The imaging conditions were as follows: tube voltage, 100 kV; tube current, 75 \(\mu\)A; magnification, \(\times\)10; slice thickness, 50 \(\mu\)m. For observation and measurement of root canals, 3-D image visualization software, VG-studio (Nihon Visual Science, Inc.) was used. Before measurement, 3-D reconstructions were prepared with the volume rendering method to observe mesiobuccal root canals. Three-dimensional reconstructions were also used to classify root canal morphology and calculate incidence.

1. **Observation of 3-D reconstructions**
   A tooth axis serving as the fiducial line for observation was defined as a straight line connecting the centroids of a triangle formed by the mesiobuccal, distobuccal, and lingual cusp tips and another triangle formed by the mesiobuccal, distobuccal, and palatal root apex (Fig. 1).\(^{3}\) This tooth axis was positioned perpendicular to the sample stage during imaging. A root canal orifice was defined as an opening on a plane perpendicular to the tooth axis at a level 3 mm towards the occlusal surface from the root furcation point, which represented a point on the furcation root surface perpendicular to the tooth axis (Fig. 2).\(^{11,18}\)

   An observation plane was defined as the center of a root canal, which represented a plane perpendicular to the tooth axis at a level one-half of the distance between the root canal orifice and root apex. Another observation plane was the apical side 3 mm, defined as the plane perpendicular to the tooth axis at a level 3 mm from the root apex towards the occlusal surface.\(^{24}\) The root apices of 3-D reconstructions were also observed. As described above, the root canal orifice, center of the root canal, apical side 3 mm, and root apex were observed. Three-dimensional reconstructions of mesiobuccal roots were also observed (Fig. 3).

2. **Classification of root canal morphology**
   To conduct classification based on numeri-
cal information on root canals, the following criteria were established:
1) Criteria for classification of main root canal (Fig. 4)
   (1) Main root canal: the maximum width of the root canal is 0.15 mm or more.
   (2) Incomplete separation root canal: separated root canals rejoin.
   (3) Upper separation root canal: ramification is located on the root canal orifice side of the level one-half of the distance between the root canal orifice and root apex.
   (4) Lower separation root canal: ramification is located on the root apex side of the level one-half of the distance between the root canal orifice and root apex.
2) Criteria for classification of accessory root canals (Fig. 4)
   (1) Accessory root canal: the maximum width of the root canal is 0.15 mm or less.
   (2) Lateral canal: extraradicular communication is located on the root canal orifice side of the apical side 3 mm.
   (3) Apical ramification: ramification is located within the apical side 3 mm.
Based on the above criteria, the 4 types of root canal configurations from the classification by Weine et al. were defined as Main Types, and ramification and lateral canal were defined as Sub Types (Fig. 4). Sample molars were classified into any combinations of these types (Fig. 5). Incidences of the respective combinations were also calculated.
Results

1. Root canal morphology

Root canal orifice: The orifices were pressed from the pulp chamber floor and formed ellipses with longer buccolingual axes. Many of them curved in the form of an arch toward the mesial side. Some of the root canal orifices strongly pressed from the pulp chamber floor divided to form multiple orifices (Fig. 6).

Center of root canal: Pressure from the distal side to this site was stronger than that on the root canal orifices, and main root canal ramifications were observed in many root canals. In the area closer to the root apex from this site, pressure on the root canal gradually decreased (Fig. 6).

Apical side 3 mm: Irrespective of whether there were main root canal ramifications, apical ramifications were commonly observed (Fig. 6).

Root apex: In most of the root canals, the positions of root apices were not consistent with those of apical foramina (Fig. 6).

Characteristics of root canal in 3-D images: Narrowing and main root canal ramifications were commonly observed from the root canal orifice to the root canal center. From the root canal center to the apical foramen, decreased pressure was observed. All root canal configurations commonly had apical ramifications.

![Fig. 6 Observation of reconstructed 3-D images by observation planes](image)


![Fig. 7 Image from mesiobuccal root canal of Japanese maxillary first molar obtained by Micro-CT imaging](image)

(A) Single root canal, (B) Upper separation root canal, (C) Lower separation root canal.
from the apical side 3 mm to the root apex (Fig. 7).

2. Incidences of root canal types (Fig. 8)

The incidence of single root canals was 40/90 teeth (44.4%), and that of incomplete separation root canals was 20/90 (22.3%). The incidence of completely separate root canals was 30/90 (33.3%), with upper separation root canals observed in 22/90 (24.4%) and lower separation root canals in 8/90 (8.9%).

Accessory root canals (apical ramifications and lateral canals) had a high incidence. The incidences of accessory root canals extending from single root canals were as follows: apical ramifications (Type I-b) 28/40, (70.0%); lateral canals (Type I-c), 1/40 (2.5%). The incidence of root canals with both types of accessory root canal (Type I-d) was 2/40 (5.0%).

Accessory root canals extending from incompletely and completely separate root canals were commonly observed. The incidences of accessory root canals extending from incomplete separation root canals were as follows: apical ramifications (Type II-b), 12/20 (60.0%); lateral canals (Type II-c), 1/20 (5.0%). The incidence of root canals with both types of accessory root canal (Type II-d) was 1/20 (5.0%).

Accessory root canals extending from upper separation root canals were as follows: apical ramifications (Type III-b), 14/22 (63.6%); lateral canals, not observed. The incidence of root canals with both types of accessory root canal (Type III-d) was 3/22 (13.6%).

The incidences of accessory root canals extending from lower separation root canals were as follows: apical ramifications (Type IV-b), 4/8 (50.0%); lateral canals (Type IV-c), 2/8 (25.0%). The incidence of root canals with both types of accessory root canal (Type IV-d) was 1/8 (12.5%).

All types of root canal ramification frequently had accessory root canals (69/90; 76.7%), and particularly root canals with apical ramifications (Type b and d) were commonly observed (65/90; 72.2%). Among them, Type III-b (apical ramification separate from upper separation root canals) was most frequent.

Discussion

Maxillary first molars have intricate anatomical configurations. In particular, the morphology of mesiobuccal root canals shows
wide variation. Treatment of the mesiobuccal root canal is, therefore, very difficult, and various methods have been used to elucidate its morphology.

Weine et al.\textsuperscript{23} observed sectioned extracted teeth and reported that the incidence of completely separate root canals was 14\% and that of incomplete separation root canals was 37.5\%. Pineda and Kuttler\textsuperscript{14} conducted a visual inspection and radiographic observation and reported that the incidence of completely separate root canals was 48.5\% and that of incomplete separation root canals was 12.2\%. Lane\textsuperscript{22} observed transparent tooth samples after the injection of dyes into root canals. The authors reported that the incidence of completely separate root canals (sum of upper and lower separation root canals) was 12.5\% and that of incomplete separation root canals \textit{(e.g.} lateral canals and apical ramifications) was 19.4\%. These reports depended on classic destructive examinations and were intended primarily for morphological classification. Weine et al.\textsuperscript{23} conducted observations based on new clinical criteria added to his own classification of root canals into 4 types\textsuperscript{23}. The authors conducted pulp chamber opening and defined main root canal ramifications as root canals into which files could be inserted until they were seen at the root apex. After inserting files, radiographs were taken with the files in place to observe root canal morphology. The authors reported the incidences as follows: single root canals, 42.0\%; complete, upper separation root canals, 30.4\%; complete, lower separation root canals, 3.4\%; incompletely separate root canals, 24.2\%. Vertucci\textsuperscript{21} used transparent tooth samples prepared by dye injection to classify root canal morphology into 8 types, without differentiating between main and accessory root canals. They reported that of the 8 types, only the following 3 were observed in the mesiobuccal root canals: single root canals, with an incidence of 45.0\%; completely separate root canal with an incidence of 18.0\%, which consisted of upper separation root canals alone; and incompletely separate root canals with an incidence of 18.0\%, which had 2 orifices and joined to form a single root canal at the center of root canal. Sert and Bayirli\textsuperscript{19} subdivided the classification by Vertucci\textsuperscript{21} and reported 15 additional types of morphological classification. This report indicated the incidences as follows: single root canals, 6.5\%; complete, upper separation root canals, 28.0\%; complete, lower separation root canals, 2.0\%; incomplete separation root canals having 6 different configurations, 63.5\%. As shown above, Vertucci\textsuperscript{21} and Sert and Bayirli\textsuperscript{19} established morphological classifications which depended on the numbers of root canals measured in respective stages from the root canal orifice to the root apex.

In the observation of sectioned extracted teeth\textsuperscript{19,21}, destruction of lateral canals or incompletely separate root canals may occur depending on the sectioned site. In a visual inspection and observation using radiographic images\textsuperscript{14}, some ramifications may be missed; therefore, observation and calculation of the exact rate of ramifications may have been difficult. The method of observing transparent tooth samples prepared by injecting dyes into the root canals facilitated the observation of root canals, and therefore, there have since been several similar reports\textsuperscript{2,12,13,15,16,19,21}. However, this method requires preparation by cleaning the contents of root canals with chemicals before dye injection, and may cause events such as insufficient staining due to the remaining contents of root canals, enlargement of the root canals due to the chemicals, and fissures in the extracted teeth due to dryness; therefore, it is presumably difficult to reproduce the original root canal morphology. The assessment of root canals using the smallest file available in actual practice is a very clinical method\textsuperscript{8}, since the presence or absence of access to the apex affects the therapeutic success; however, there have been no reports on lateral canals which could not be radiographed with files in place. The classifications by Weine et al.\textsuperscript{23}, Vertucci\textsuperscript{21}, and Sert and Bayirli\textsuperscript{19} are excellent for identifying root canal morphology, but do not address the differentiation of the observed structures.
This study classified root canal morphology using Micro-CT and calculated the ramification rate. Since conventional methods do not allow for nondestructive measurement of tooth structures, it was difficult to establish clear criteria for classification. Moreover, the definitions of root canal structures varied depending on the literature and had poor reproducibility. In this study, however, we successfully performed nondestructive classification based on numerical criteria by observing root canal morphology in 3-D reconstructions produced by Micro-CT images and by measuring root canal diameters and ramification sites.

In this study, the incidences of single root canals and separate root canals (completely and incompletely separate root canals) were similar (single root canal, 44.4%; separate root canal, 55.6%) to mean values (single root canal, 43.1%; separate root canal, 56.8%) in earlier studies. Accessory root canals (apical ramifications and lateral canals) had a high incidence (76.7%). Root canals with several types of accessory root canals were also observed.

In each type of main root canal ramification, the occurrence of apical ramifications (Type b and Type d classification in this study) was frequently observed (72.2%). This result is presumably explained by the fact that the conventional methods encountered difficulty in observing apical ramifications measuring 0.15 mm or less in diameter, although main root canal ramifications and lateral canals with large diameters could be detected. For example, in the method for observation of transparent tooth samples prepared by injecting dyes into the root canals, complete staining of the root canals is difficult, since the contents of the root canal cannot be completely removed and dyes do not permeate apical ramifications where complete removal of the contents is difficult. In contrast, Micro-CT requires no destructive preparation and can visualize structures of 2 μm in size at minimum. This may explain why microscopic apical ramifications could be observed accurately. Moreover, 3-D reconstructions are superior to conventional samples in observation and measurement in any direction; therefore, the high incidence of apical ramifications seen here may be explained by ramifications previously categorized into other morphological types being accurately reclassified as apical ramifications.

Knowledge of root canal variations will assist the dentist in reaching conclusions when diagnosing and treating endodontic problems.

Conclusions

This study classified root canals based on numerical criteria using images obtained by Micro-CT. In addition, previously unclear root canal morphology was systematically subdivided. The results demonstrated that the incidence of accessory root canals, particularly apical ramifications, was higher than that in earlier reports.

References

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