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Original

Morphologic Classification of Root Canals and Incidence of Accessory Canals in Maxillary First Molar Palatal Roots: Three-Dimensional Observation and Measurements using Micro-CT

Satoru Matsunaga[1,2)]*, Yoshiaki Shimoo[1)]*, Hideaki Kinoshita[1)], Masashi Yamada[3)], Akinobu Usami[4)], Yuichi Tamatsu[5)] and Shinichi Abe[1)]

[1)] *Department of Anatomy, Tokyo Dental College, Tokyo, Japan*
[2)] *Division of Oral Implants Research, Oral Health Science Center, Tokyo Dental College, Tokyo, Japan*
[3)] *Department of Endodontics, Pulp and Periapical Biology, Tokyo Dental College, Tokyo, Japan*
[4)] *Division of Oral Anatomy Department of Morphological Biology, Ohu University School of Dentistry, Koriyama, Japan*
[5)] *Department of Neurology, Gross Anatomy Section, Kagoshima University Graduate School of Medical and Dental Sciences, Kagoshima University Dental School, Kagoshima, Japan*
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Abstract: The purpose of this study was to examine the incidence of root canals with ramifications and accessory root canals close to the apical area of the palatal root of maxillary first molars, and to classify them based on morphology. Using Micro-CT, we created images of 90 extracted Japanese maxillary first molars that were free of caries and other anatomical defects, and conducted three-dimensional observation and measurements in order to classify root canals with ramifications and accessory root canals. None of the root canals in palatal roots of maxillary first molars were completely separated, and all of them were single canals. As for the incidence of root canals with ramification, we found that Type I-a, in which there were no accessory root canals, comprised 65.6 %, while Type I-b, which showed apical ramifications, comprised 31.1 %, and Type I-c, which had lateral canals, comprised 3.3 %. Observation of the cross-section morphology of the root canals revealed strong buccolingual constriction at the root canal orifice, but other than that, the canals had an elliptical shape with a large mesiodistal width. Maxillary first molar palatal roots contain single canals, but strong constriction is observed at the root canal orifice, and accessory root canals are frequently observed in the apical area. These findings indicate the necessity for adequate mechanical and chemical enlargement of the root canal and orifice.

Key words: Canal configuration, Maxillary first molar, Micro-CT, Palatal root canal, Root canal anatomy

Introduction

Root canal treatment of maxillary first molars is considered to be difficult even with the wide use of microscopes and various other new instruments designed for root canal treatment[1-3]. The main reason is that maxillary first molars have three roots, and also the root canals frequently have ramifications, as well as accessory root canals[4-6]. In particular, a large number of clinical reports described abnormal root canal configurations in mesiobuccal roots, as well as the treatment of such canals, and in some of these cases, the prognosis was poor[7-11]. By contrast, palatal roots of maxillary first molars are relatively straight, and have comparatively large single canals[4-6]. However, Holderrieth et al. have described morphological aberrations in palatal root canals of maxillary first molars, and have indicated that retreatment of the root canal may become necessary[12]. A number of clinical reports found in the literature described root canals with ramifications in maxillary first molar palatal root canals[13-16], but it is difficult to detect accessory root canals when performing root canal treatment.

Maxillary first molar root canal morphology has been observed using X-ray images of extracted teeth and transparent tooth specimens, and numerous reports have described ramifications of main root canals with large diameters and lateral canals. At the same time, because it is difficult to detect microstructures, particularly in apical areas, using conventional techniques, it is believed that there could still be anatomical features that affect the precision of root canal treatment. In recent years, however, with the availability of micro-CT, which features high resolution imaging, three-dimensional observation and measurement of microstructures in hard tissue are being carried out much more

*These authors contributed equally to this work.
Correspondence tor: Dr Satoru Matsunaga, Department of Anatomy, Tokyo Dental College, 2-9-18, Misaki-cho, Chiyoda-ku, Tokyo 101-0061, Japan; Tel: +81-3-6380-9592; Fax: +81-3-6380-9664; E-mail: matsuna@tdc.ac.jp

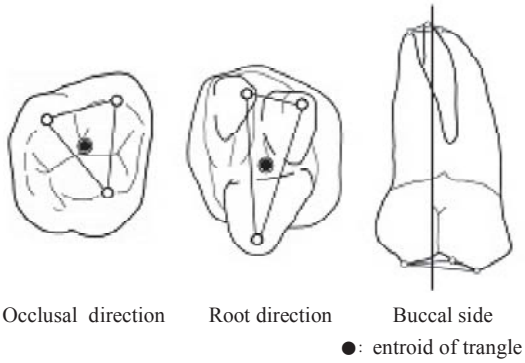


Figure 1. The tooth axis. The tooth axis was defined as a straight line connecting the centroids of a triangle formed by the mesiobuccal, distobuccal and lingual cusp tips and another triangle formed by the mesiobuccal, distobuccal and palatal root apices.

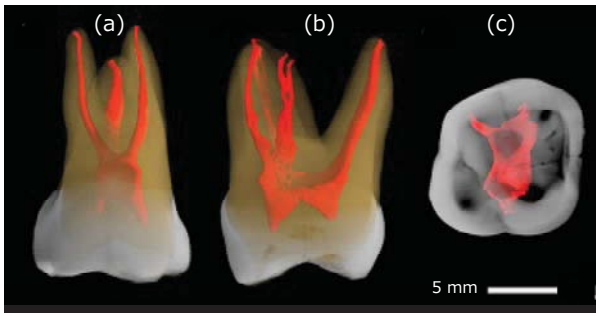


Figure 2. Observation of the pulp cavity which was reconstructed three-dimensionally. (a): Buccal side; (b): Mesial side; (c): Occlusal direction (white: enamel, yellow: dentin, orange: pulp)

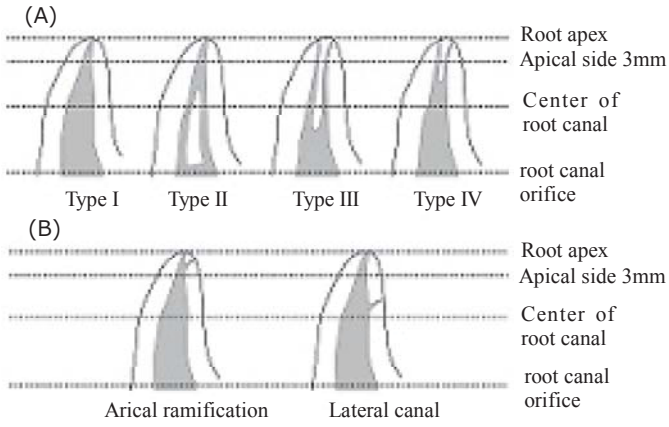


Figure 3. Weine's classifications of root canals (1969). (A): Main root canal type; (B): Accessory root canal type.

obtain detailed data regarding apical microstructures. As a result, it is anticipated that new knowledge can be gained about maxillary first molar palatal roots.

In this study, we observed and measured root canals with ramifications and accessory root canals in the apical area of maxillary first molar palatal roots using micro-CT, with the aim of classifying maxillary first molar palatal root canals and calculating the ramification ratio based on those classifications.

Materials and Methods

A total of 90 extracted Japanese maxillary first molars free of caries and other anatomical defects, which were stored at the Department of Anatomy, Tokyo Dental College, were used. This research is allowed by our Institution. Images of the samples were created using micro-CT (HMX225-ACTIS4, TESCO, Tokyo, Japan). The imaging conditions were as follows: tube voltage: 100 kV, tube current: 75 μA, magnification: ´10, slice thickness: 50 μm.

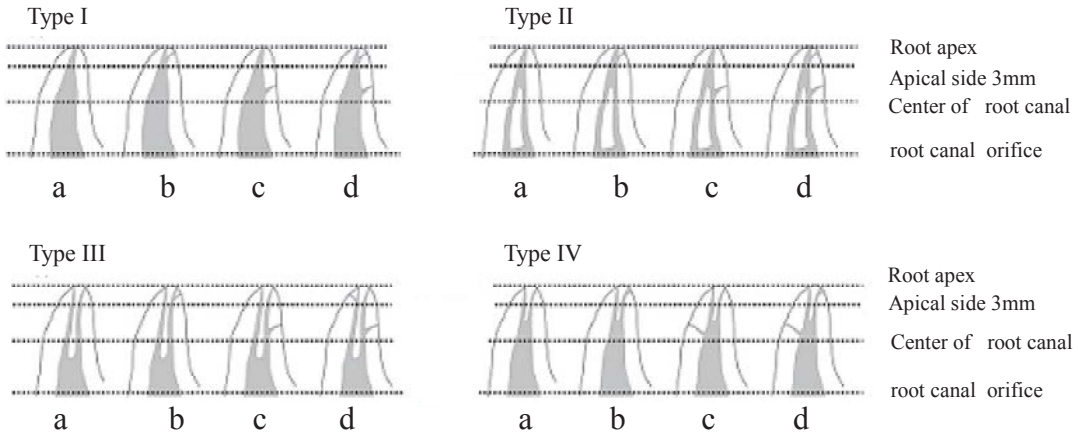


Figure 4. Classifications with accessory canal types added to Weine's classifications.
a: No accessory root canals;
b: With apical ramifications;
c: With lateral canals;
d: Both apical ramifications and lateral canals observed at the same time.

frequently[17,18]. Analysis using micro-CT is nondestructive, and, unlike earlier classic techniques, makes it possible to reliably

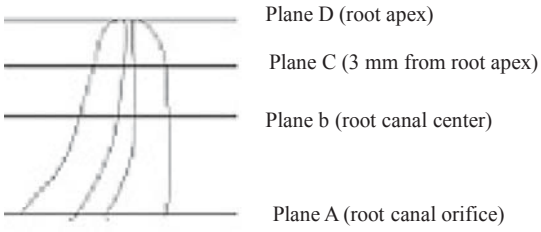


Figure 5. Measurement sites on the root canal transverse planes.

interest was observed and measured (VG-Studio MAX, Volume Graphics, Heidelberg, Germany).

Setting the area of interest and measurement items

After binarization processing had been carried out and the dentin and pulp cavity had been separated, the pulp cavity was reconstructed in red to enable three-dimensional morphological observation (Fig. 2). Observation items included the curvature

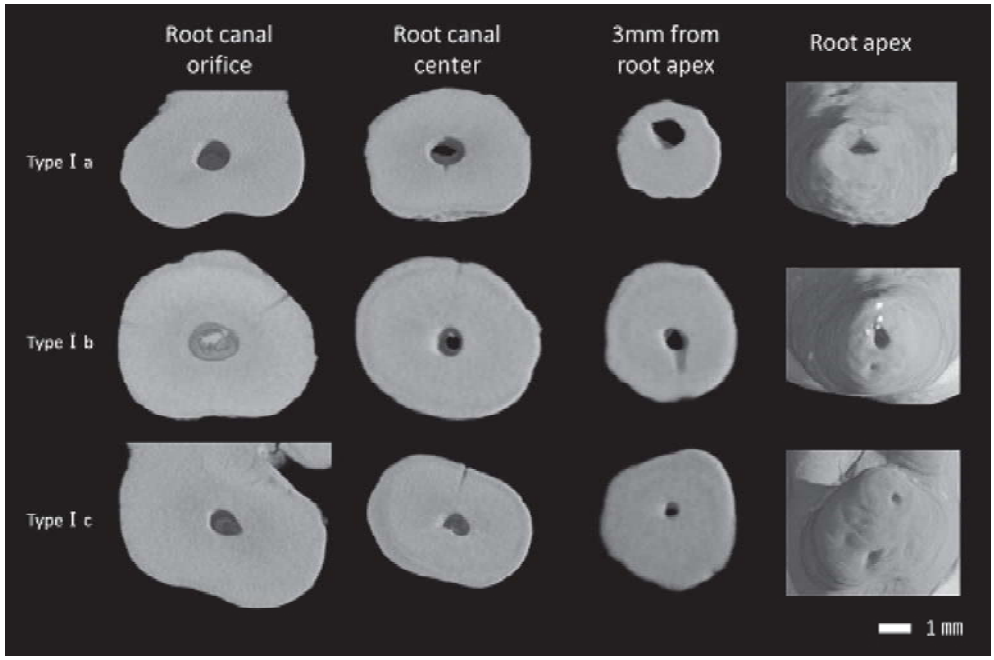
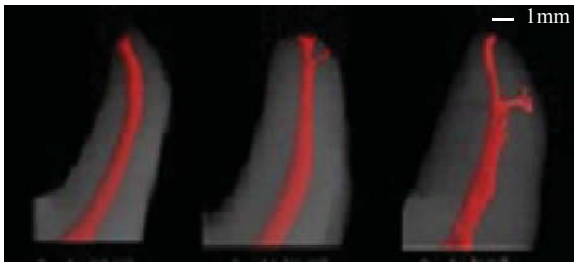


Figure 6. Slice images of maxillary first molar palatal root canals at the root orifice, center, 3mm from root apex and root



Type Ia (65.6%) Type Ib (31.1%) Type Ic (3.3%)

Figure 7. Morphology of maxillary first molar palatal root canals, and incidence of accessory canals.

Micro-CT imaging and three-dimensional reconstructions

A straight line connecting the centroids of two triangles; first triangle formed by the mesiobuccal, distobuccal and lingual cusp tips and the other formed by the mesiobuccal, distobuccal and palatal root apices, was set as the tooth axis (Fig. 1) [19, 20]. For imaging, the samples were positioned in such a way that the tooth axis was perpendicular to the micro-CT sample stage. Using the volume rendering method, three-dimensional reconstructions were prepared from the slice data that was obtained, and the area of

and constriction of the root canal, the locations of root apices and apical foramina, and the root canal morphology (the presence/absence and locations of root canal with ramifications and accessory root canals). We added a few more criteria to the root canal classification by Weine et al., and calculated the root canal ramification ratio[11]. Fig. 3 shows the classification criteria for the main root canal morphology, while Figure 4 shows the classification criteria for accessory root canals. We also measured root canal widths categorized by location. The planes that passed through the center of the root canal orifice and the root apex of the maxillary first molar palatal root and that intersected the tooth axis at right angle were defined as Plane A and Plane D, respectively, while the plane intersecting the tooth axis at right angle at one-half of the distance between the root orifice and the root apex was defined as Plane B, and the plane at a distance of 3 mm from the root apex was defined as Plane C (Fig. 5)[21]. The root canal widths (long and short diameters) were measured on Planes A, B and C.

Results

Observation of palatal root canal morphology

In many palatal root samples, the main root was curved between the center of the canal and the root apex, with the curvature in various directions, such as the buccal direction, or toward the palatal direction. In the cross-section morphology of the root canals, strong buccolingual constriction was observed at the root canal orifice, but aside from that, canals appeared elliptical in the distobuccal direction. In a majority of cases, the positions of root apices were not consistent with those of apical foramina (Fig. 6). Figure 7 shows the results of root canal classification. In maxillary first molar palatal roots, none of the canals were completely separated, and most of the canals were Type I, which are single canals. As for the incidence of root canals with ramifications, Type I-a, in which there are no accessory root canals, comprised 65.6 %, while Type I-b, which show apical ramifications, comprised 31.1 %. Type I-c, which show lateral canals, demonstrated the lowest incidence at 3.3 %.

Root canal widths classified by site

Regarding the cross-section width of the root canals, for Plane A, the mean shortest diameter was 0.76 mm and the mean longest diameter was 1.15 mm, while for Plane B, the mean shortest diameter was 0.53 mm and the mean longest diameter 0.74 mm. For Plane C, the mean shortest diameter was 0.47 mm and the mean longest diameter 0.66 mm.

Discussion

The roots of the maxillary first molar have intricate anatomical configurations and various methods have been used to elucidate its morphology. In particular, the palatal root apex of the maxillary first molar is close to the maxillary sinus, and is frequently responsible for maxillary sinusitis of dental origin. Therefore, it is extremely important to identify anatomical structures in the region close to the root apex, with the aim of increasing the success rate of endodontic treatment in maxillary first molar palatal roots. First of all, in our study, we did not observe aberrations in the number of main root canals as reported earlier by Holderrieth et al[12]. Reports by Wong et al. and Maggiore et al. mention that all were single canals[14,16], so, as reported in the abovementioned study, cases with two or more palatal root canals may be extremely rare. As for the percentage of palatal root canals that have apical ramifications, Okumura et al. reported an incidence rate of more than 20 % in Japanese maxillary first molar palatal roots[22], which is relatively high, and the rate of over 30 % observed in our study is considerably higher than rates indicated in earlier studies. The three-dimensional analysis using micro-CT, which has a maximum imaging resolution of 5 μm, made it possible to identify extremely fine apical ramifications, leading to our assumption that there is an extremely high incidence rate of root canal lateral branches in palatal roots. At the same time, although the percentage of root canals with accompanying lateral canals was low, at 3.3 %, it cannot be ignored. Not only are apical ramifications and lateral canals observed in nearly 35 % of all teeth, but in more than half of root canals, the positions of root apices are not consistent with those of apical foramina. This means that when the root canal is enlarged, cleaned and formed, the morphology of maxillary first molar palatal roots may prevent proper completion of the procedure. Moreover, although no drastic narrowing was observed when comparing roots on the mesiobuccal side and the distobuccal side, the buccolingual constriction on the root canal orifice of palatal roots was extremely strong, and because the orifice gradually becomes elliptical in shape as it approaches the root apex, it is necessary to sufficiently enlarge the root canal orifice. With flattened root canals, however, it can be difficult to perform adequate mechanical preparation using an SS file or Ni-Ti rotary file. For this reason, it may be necessary to perform mechanical preparation using a microscope and an ultrasound tip, or to use a chemical agent as well. It has been reported, however, that once treatment of the infected root canal had been performed, and apicoectomy had been done, in many cases in which the results of pathologic examination led to the diagnosis of apical cyst, lateral canals were observed at the root apex[23]. Therefore, it must be said that there are limits to what can be achieved by approaching the root apex from within the root canal. In palatal roots with a poor prognosis for root canal treatment, surgical treatment must be considered, along with the other two roots.

Acknowledgments

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