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Comparison of root canal filling quality by mineral trioxide aggregate and gutta percha cones/AH plus sealer

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The aims of this study were to evaluate the quality of canal filling using mineral trioxide aggregate (MTA) and gutta-percha (GP) in root canals, and to investigate the differences in the percentage of voids between mesial and distal canals by using microcomputed tomography. Twenty-two extracted human mandibular molars were instrumented using rotary files. Two teeth without canal fillings served as negative controls, and the other teeth were obturated with either ProRoot® MTA or gutta-percha and AH Plus® sealer. Obturated teeth were scanned with microcomputed tomography, and the percentage of voids (V%) was calculated. These specimens were also examined under a scanning electron microscope. The MTA group showed a significantly higher V% than the GP groups (p<0.05). The mesial canal groups showed significantly higher V% than did the distal canal groups (p<0.05). In orthograde filling, MTA exhibited significantly lower filling quality than did GP.

Keywords: Canal filling, Gutta percha, Micro-CT, MTA, Sealing

INTRODUCTION

The material used for root canal obturation is one of the critical determinants of the success or failure of endodontic treatment. For the last century, gutta-percha in combination with a sealer has been used as the primary root canal-filling material, owing to advantages such as adequate obturation of the root canal space, favorable handling characteristics, and biocompatibility[1)]. However, when gutta-percha canal fillings were tested *in vitro* by using models of dye penetration, fluid filtration, or bacterial leakage[2-5)], some vulnerability was observed, especially with regard to coronal microleakage.

Therefore, other materials have been investigated to assess their eligibility as a root canal-filling material. Recently, mineral trioxide aggregate (MTA) was evaluated as an orthograde canal-filling material[6,7)]. MTA was introduced by Torabinejad and his group in the 1990s[8)]. MTA was proven to have favorable physical, chemical, and biologic properties[9-11)], and it has been widely used for perforation repair[12,13)], retrofilling, pulp capping, and apexification[14)]. Bogen and Kuttler suggested that MTA can be used as an alternative to gutta-percha cones and reported successful cases in which roots were obturated with MTA[6)]. Interestingly, in the same study, these authors presented micro-computed tomography (micro-CT) images of MTA filling, but with voids[6)]. Indeed, few studies have investigated the sealing ability of MTA as an orthograde canal filling material or the retreatability of MTA. Some studies reported that when MTA is used for orthograde root canal filling, its sealing ability is inferior[15)] or superior[16)] to that of gutta-percha. A few studies have shown that MTA is an effective root reinforcement material[17,18)]. However, one of the drawbacks of MTA is the difficulty of its handling. On mixing, MTA becomes a slurry paste that is difficult to handle and compact into narrow and confined root canal spaces without creating voids. The sealing ability of any material might be negatively influenced by the presence of voids between its particles.

In this context, we hypothesized that there is no difference in the quality of canal filling performed with gutta-percha and sealer and that performed with MTA. To evaluate the quality of canal filling, micro-CT has been used more recently, since this method enables analysis of the voids without destroying tooth structure[19,20)]. A quantitative analysis by micro-CT was utilized in the present study to locate and calculate the voids after canal filling. Therefore, the aims of this study were as follows: (1) to evaluate and compare the percentage of voids in 5 mm apical canals filled by MTA with those filled by gutta-percha/AH plus sealer, (2) to separately compare the percentage of voids in mesial and distal canals depending on the filling materials, and (3) to investigate the differences in the percentage of voids between mesial and distal canals.

Color figures can be viewed in the online issue, which is available at J-STAGE.

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MATERIALS AND METHODS

Preparation of teeth samples

For this study, we used 22 freshly extracted human mandibular molars with fully formed apices. The teeth were extracted for orthodontic and periodontal reasons, and the protocol was approved by the institutional review board (IRB) in our institution (IRB approval no: 2-2015-0150). The inclusion criteria for the teeth were as follows: (1) Two canals in the mesial root and a single canal in the distal root, (2) root curvature between 0° and 20°, (3) no previous root canal treatment, and (4) no signs of cracks, perforation, internal resorption, external resorption, or root caries. To assess the internal resorption and curvature of the root canals, periapical radiographs were taken from both the buccolingual and mesiodistal directions. The degree of root curvature was calculated from the buccolingual radiographs using the method described by Schneider[21].

The crowns were cut with a high-speed bur under copious water spray such that equal lengths of 12 mm were achieved. After access preparation, a size 10 or 15 K-file (Dentsply Maillefer, Ballaigues, Switzerland) was inserted into the canal until it could be visualized at the apical foramen; the working length was determined by subtracting 0.5 mm from this length. Radiographs were taken to confirm the working lengths and check the canal configurations. The mesial canals of Weine type II and III were used in the study. All the canals were instrumented with a ProFile® NiTi system (Dentsply Maillefer) to a master apical size of #35/06 in a crown-down manner. Each canal was irrigated using 10 mL of a 2.5% sodium hypochlorite (NaOCl) solution and a 27-gauge needle between the instrumentations. When the instrumentation was completed, the canal was irrigated with 1 mL of 17% ethylenediaminetetraacetic acid (EDTA) for 1 min, followed by 5 mL of 2.5% NaOCl. All the canals were dried with absorbent paper points (Meta Dental, Cheongju, Korea). Next, the teeth were randomly assigned to 2 groups (n=10), according to the obturation material used. Teeth without canal fillings (n=2) were used as negative controls in order to determine the density range for the micro-CT analysis.

1. MTA group

Freshly mixed tooth-colored ProRoot® MTA (Dentsply Tulsa Dental, Tulsa, OK, USA) was prepared according to the manufacturer's instructions and delivered into the canal using a specialized MTA delivery gun (diameter: 0.90 mm, Micro-Apical Placement (MAP) System®, Dentsply Tulsa Dental). Next, MTA was first incrementally packed into the root canals using Obtura S-Kondensers (Obtura Spartan, Earth City, MO, USA), and the extra moisture was absorbed with paper points. In the apical area, a #40 tip size of the Obtura S-Kondenser and the apical portion of a coarse-sized paper point (diameter: 0.37 mm) were used. The tip of #40 S-Kondenser reached 1 mm short from the working length. Using up-and-down motion, a MTA pellet placed by the MTA delivery gun was packed by the S-Kondenser. In the middle area, a #50 tip size of the Obtura S-Kondenser and the apical portion of a coarse-sized paper point were used. In the coronal area, a #60 or larger tip size of the Obtura S-Kondenser and the coronal portion of a fine-sized paper point (approximate diameter: 0.8 mm) were used.

2. GP group

The prepared root canals were filled with medium-sized gutta-percha cones (Diadent, Seoul, Korea) and AH Plus® sealer (Dentsply Detrey, Konstanz, Germany) using a continuous wave vertical compaction technique with a System B® (Courtesy SybronEndo, Orange, CA, USA) and SuperEndo Beta 2® backfill system (B&L Biotech, Ansan, Korea).

All canal-filling procedures were performed under a dental microscope (OPMI PICO, Carl Zeiss, Gottingen, Germany) at 10× magnification. Obturated teeth were examined radiographically to confirm the canal filling state, and none of the teeth exhibited an incomplete canal filling state. All the specimens were stored at 100% humidity and room temperature until the micro-CT scan. Furthermore, the teeth were embedded in clear resin, horizontally sectioned at 1, 3, 5, and 7 mm from the apex, and processed for scanning electron microscopy (SEM). All the specimens were prepared by one operator.

Micro-CT evaluation

A SkyScan 1172 high-resolution micro-CT scanner (SkyScan, Kontich, Belgium) was used to scan the teeth. The micro-CT scanner had a pixel size of 30 µm, X-ray source voltage of 100 kV, beam current of 100 µA, aluminum filter thickness of 0.5 mm, rotation step of 0.4° per step, and exposure time of 316 ms. Images obtained from the scan were reconstructed with the NRecon (Skyscan) software. CT-An (SkyScan) was used to measure the volume of the gap between the filling material and the tooth structure. The range of measurements was 5 mm apical from 1 mm coronal to the root apex. Within that range, a density between 86 and 255 Grayscale was assigned as the volume of the filling material (V_M) and a density between 0 and 25 Grayscale was assigned as the volume of the voids (V_V). Then, the percentage of voids (V%) was calculated as $V_v/(V_v+V_M)\times100$ (Fig. 1). To evaluate the overall filling state, three-dimensional (3D) images of the filling material were visualized by CT-Vol (SkyScan).

SEM evaluation

The sectioned specimens were coated with gold by ion sputter (IB-3, Eiko, Japan) and examined by SEM (FE SEM S-800, Hitachi, Tokyo, Japan) at various magnifications.

Statistical analysis

The Mann-Whitney test was used to determine the significances of the following differences: (1) the V% of the MTA and GP groups, (2) the V% of the MTA and GP groups within the mesial canal groups, and (3) the

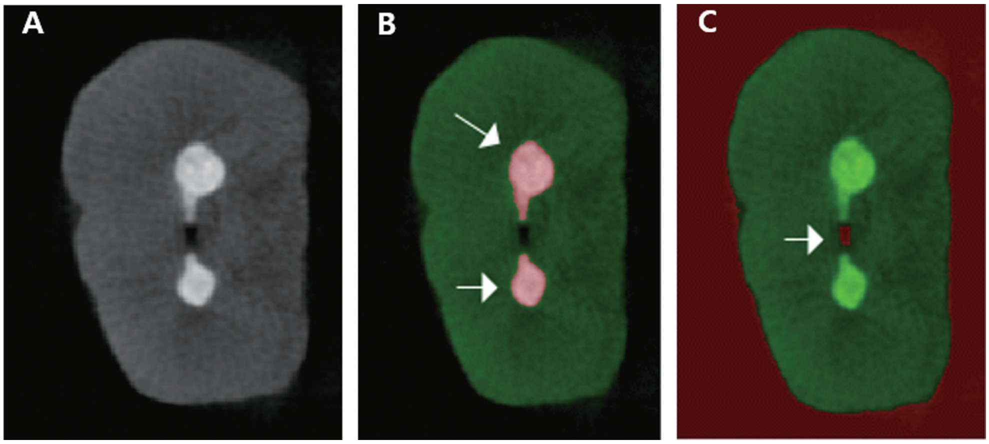

Fig. 1 Procedure for the calculation of the percentage of voids (V%) with CT-An.
(A) Original micro-CT scan image. (B) Program setting for capturing the density between 86 and 225 Grayscale (marked by a white arrow). The volume of this area was considered the volume of the filling material (V_M). (C) Program setting for capturing the density between 0 and 25 (marked by a white arrow). The volume of this area was considered the volume of voids (V_v). The percentage of voids (V%) was calculated by using the formula $V_v/(V_v+V_M)\times100$.

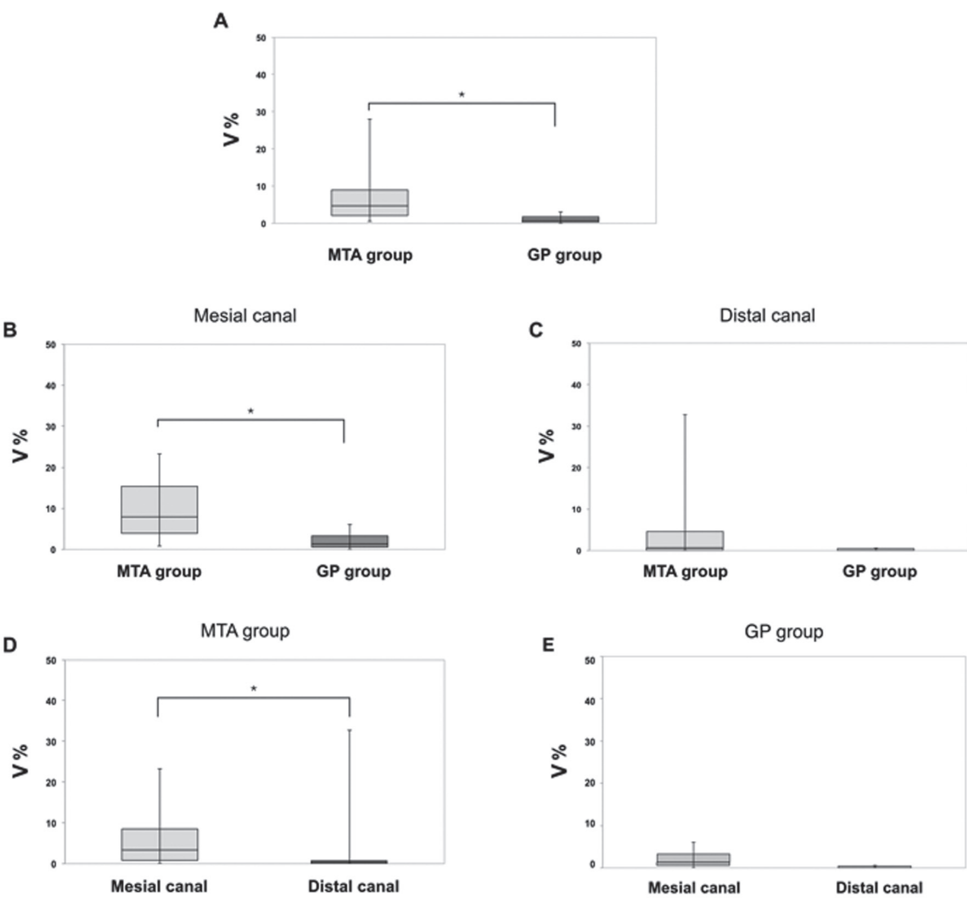

Fig. 2 Box plots of the percentage of voids (V%) of the MTA and GP groups (A) for both types of canals, (B) for the mesial canal groups, and (C) for the distal canal groups.
Box plot of V% of the mesial canal and distal canal groups for the MTA (D) and GP (E) groups.
* indicates a significant difference between the groups.

V% of the MTA and GP groups within the distal canal groups. Additionally, the Wilcoxon signed-rank test was performed to analyze the differences between the following: (1) the V% of the mesial and distal canal groups, (2) the V% of the mesial and distal groups within the MTA groups, and (3) the V% of the mesial and distal canal groups within the GP groups.

The significance level was set at $p<0.05$. The statistical analyses were performed using SPSS software version 20 (SPSS, Chicago, IL, USA).

RESULTS

The MTA groups presented significantly higher V% than did the GP groups ($p=0.002$, Fig. 2A). A comparison of the MTA and GP groups within the mesial canal groups revealed that the MTA groups showed significantly higher V% ($p=0.002$, Fig. 2B). However, within the distal canal groups, the MTA and GP groups exhibited no statistically significant difference ($p=0.123$, Fig. 2C).

When comparing V% of the mesial canal and distal canal groups, the mesial canal groups exhibited significantly higher V% than did the distal canal groups ($p=0.001$, Fig. 2D). The same pattern of results was observed within both the MTA and GP groups ($p>0.05$, Fig. 2E).

The overall filling state was revealed by the 3D image of the filling material (Fig. 3). In the GP groups, the 3D image revealed a homogenous filling state (Fig. 3A) and almost perfectly obturated isthmus areas (Fig. 3B). In the MTA groups, an irregular filling state was observed on the 3D image (Fig. 3C), particularly in the isthmus and apical areas. In the sectional image, the unfilled space in the isthmus area (Fig. 3D) and the plugger mark under the curvature were evident (Fig. 3E).

SEM revealed filling defects in the mesial canals of the MTA group (Fig. 4A) and favorable seals in the distal canals of the MTA group (Fig. 4B). Most specimens in the GP group showed tight sealing (Figs. 4D and E). Interfaces between filling materials and the dentin surface were examined, and no specific differences were found (Figs. 4C and F).

DISCUSSION

Under the conditions of the present study, the quality of canal filling produced by the traditional gutta-percha technique was found to be superior to that produced by MTA. The high percentage of voids produced by MTA might be attributed to its poor handling characteristics. The first possible reason is the delivery and packing system used in MTA fillings. We used an MTA delivery gun, endodontic plugger, and a paper point to pack the MTA paste and absorb the excess water. The endodontic plugger may become covered with the MTA

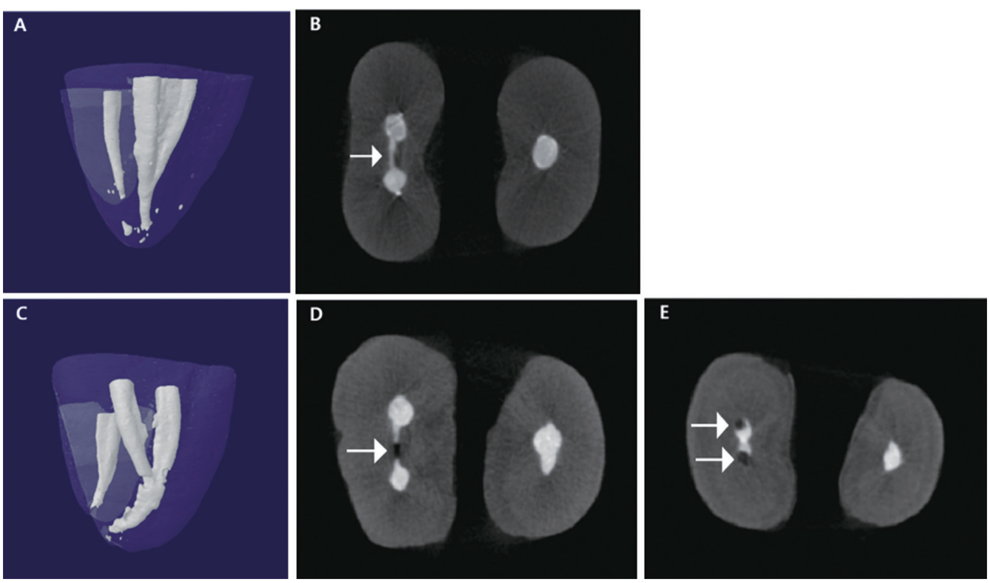

Fig. 3 3D and sectional images of the MTA-filled and GP-filled teeth in the apical 5 mm region of the canal.
(A) 3D image of the GP-filled tooth in the 5 mm apical region of the canal. (B) Sectional image of the same tooth as (A), in which the isthmus area is well obturated with material (indicated by the white arrow). (C) 3D image of the MTA-filled tooth in the 5 mm apical region of the canal. (D) Sectional image of the same tooth as (C), in which the isthmus area remained unfilled. (E) Sectional image of the same tooth as (C); the white arrows indicate the voids in the filling material, suggesting a plugger mark.

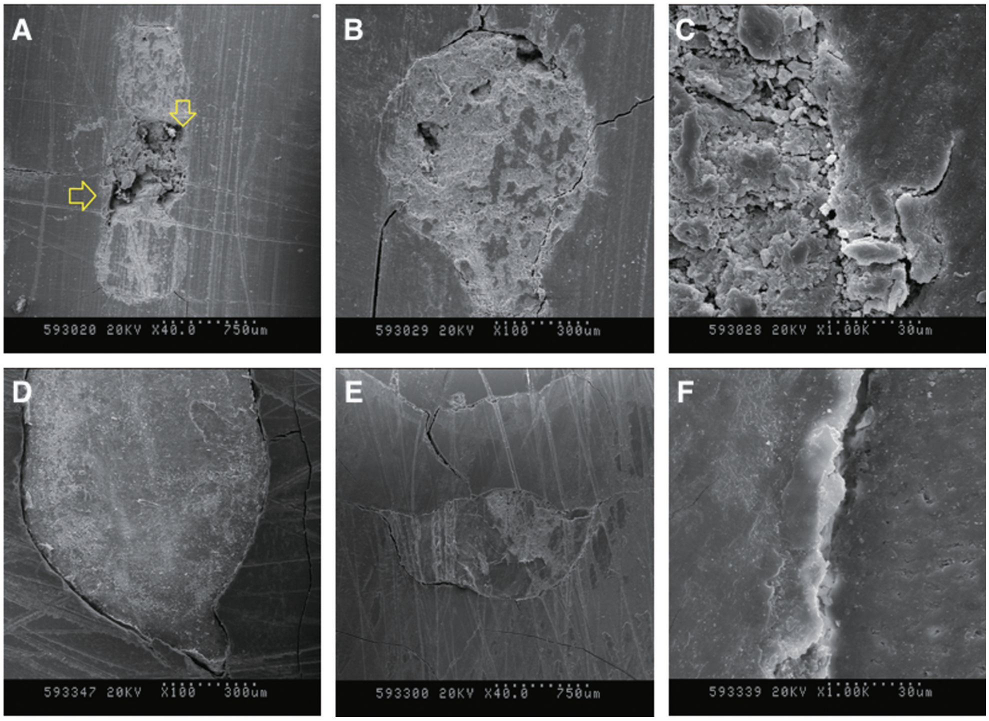

Fig. 4 Photographs taken by SEM.
(A) A mesial canal filled with MTA at the 3 mm level showed defects (indicated by arrows). (B) A distal canal filled with MTA at the 3 mm level. (C) An interface between MTA and dentin. (D) A mesial canal filled with gutta-percha and AH Plus sealer at the 3 mm level. (E) A distal canal filled with gutta-percha and AH Plus sealer at the 3 mm level. (F) An interface between gutta-percha plus sealer and dentin.

slurry paste and create a void because of the packing motion. The plugger mark was observed in some micro-CT images (Fig. 3E). To compensate for the weakness of the endodontic plugger, a paper point was utilized to pack the MTA paste while absorbing the extra moisture. Another possible reason for the low sealing ability with MTA is the absence of a sealer. When gutta-percha is used in combination with a sealer, the sealer fills the gaps between the gutta-percha and the canal as well as other complex anatomical parts (*e.g.*, isthmuses, accessory canals, fins, anastomoses, apical deltas, and other irregularities of the root canal space). Furthermore, orthograde filling with MTA might be technique sensitive, which might explain the large interquartile range of the percentage of voids that were observed in our data for the MTA group. These results imply a possible clinical situation in which internal voids and gaps are left between the filling material and the canal wall in a case-dependent manner.

Our results are consistent with those of Vizgirda *et al.*[15], who reported that the apical seal produced by traditional gutta-percha techniques was superior to that produced by MTA. In contrast, Al-Hezaimi *et al.*[16] reported that orthograde filling of a root canal with MTA may be more resistant against human saliva leakage than vertically condensed gutta-percha and sealer. Differences in the methodology used for measuring the sealing ability might have contributed to the variations in the results of these studies.

In the present study, the mesial canal group showed significantly higher gap formation than the distal canal group, regardless of the filling material. This result might be attributable to differences in the morphology of the mesial and distal canals. Typically, mesial canals have more severe root curvature and isthmuses that are difficult to fill. In this study, we included teeth with mesial canals of only Weine types II and III, which contain isthmuses. Clinically, the results suggest that it might be more difficult to compact a mesial canal than a distal canal, regardless of the filling material.

Within the mesial canal groups, the GP groups showed lower volume of gaps than did the MTA groups. We used a continuous wave vertical compaction technique for the GP groups. With this technique, thermoplasticized GP can flow into irregularities in the root canal space. For this reason, GP may be advantageous for complex canal types. However, the flowability of the MTA paste was inferior to that of GP; therefore, MTA could not reach small complex spaces such as the isthmus. Moreover, micro-CT images showed that most of the isthmus space was filled with material in the GP group, but considerably large areas in the isthmuses remained unfilled in the MTA group.

These results indicate that much more caution is required when MTA is used to perform orthograde fillings of complex canal types and that the possibility of the formation of gaps in small irregularities needs to be considered.

Within the distal canal groups, MTA and GP were not different in terms of root canal filling quality, and the median $V\%$ was very low. However, these findings do not indicate that both MTA and GP provide high-quality and stable seals. Within the MTA groups, the interquartile range was much larger than that of the GP groups, which indicates that MTA filling does not always provide appropriate filling quality.

We only measured the apical 5 mm of the canal because this measurement might be more clinically relevant in terms of root canal treatment success than measurements of the full canal length. In a previous study[22)], the filling quality in apical canals was found to be significantly worse than that of coronal canals, regardless of the filling material. Thus, had we analyzed the full length of the canals, our results might have indicated a good filling quality, particularly in the MTA groups, and it might have shown no significant differences between the MTA and GP groups.

This study has some limitations. The distances and sizes of the isthmuses between the mesial canals could not be controlled when the specimens were randomized. Moreover, the small sample size, MTA placement technique, and operator's workmanship might have affected the results. A few studies have reported that the MTA placement technique[23)] and vehicle[24)] may affect the sealing ability.

The micro-CT analysis used in the present study provided a clear understanding of the location and volumetric measurements of gaps and internal voids because of its highly accurate and nondestructive characteristics[25,26)]. Previous studies in this field have had the limitation of measuring and calculating the percentages of the surface areas of the filling materials and voids by analyzing the root sections and using digital imaging software. These techniques might be inaccurate because some filling material might be lost in the process and because 2D techniques cannot be accurately applied to measure a 3D structure. The present study is one of the first to use micro-CT to measure the percentage of the surface and the volume of voids and gaps in root canals filled with MTA or GP.

CONCLUSIONS

The results of the present study show that the use of MTA as an orthograde filling material produced significantly higher percentage of voids than did GP. Moreover, with MTA, several voids were observed in the area of the isthmus or as plugger marks. MTA exhibited significantly poorer sealing quality in mesial canals in human mandibular molars, which are complex canal types; however, this difference was not observed in the simple-type distal canals. Thus, we do not recommend the use of MTA for routine canal filling.

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