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ORIGINAL ARTICLE

Evaluation of three obturation techniques in the apical third of mandibular first molar mesial root canals using micro-computed tomography

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filled volume ratio;
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Abstract *Background/purpose:* Recent studies have demonstrated a high incidence of isthmuses in mandibular first molar mesial roots, and intratubular mineralization following mineral trioxide aggregate obturation. This study assessed the filling quality of three obturation techniques in the apical 5 mm of mandibular first molar mesial root canals.
Materials and methods: Sixty extracted human mandibular first molar mesial roots with two separate canals that had interconnecting isthmuses, were prepared to an apical size of 40/0.06. They were allocated to three groups of 20 roots for obturation by either cold lateral compaction (CLC) or the continuous wave of condensation (CW) that used gutta-percha and AH Plus sealer, or by an orthograde canal obturation using OrthoMTA. The obturated roots were scanned by micro-computed tomography and assessed for the volumetric ratio (%) of gutta-percha, sealer, and OrthoMTA within the main canals or isthmuses in the apical 5 mm area. Measurements were analyzed statistically for differences among three obturation techniques.
Results: In the main canals, filled volume ratios were not significantly different among groups. Within isthmuses, the filled volume ratio for CLC was lower than in CW ($P = 0.025$) or

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OrthoMTA ($P = 0.002$). In isthmuses, the gutta-percha volume ratio in CLC was lower than in CW ($P = 0.005$), although the sealer volume ratio was higher than in CW ($P = 0.049$).

Conclusion: CLC demonstrated lower filling densities in isthmuses in the apical region than either CW or OrthoMTA. Orthograde MTA obturation showed comparable filling quality to gutta-percha with sealer.

Introduction

The main purpose of root canal obturation is to obtain a three-dimensional seal of the entire canal system that prevents communication between the root canal and periapical tissue.[1] However, it is difficult to achieve this goal because of intricate anatomy in the canals. Isthmuses are a thin communication between two or more canals within the same root.[2] They are inaccessible to instruments and harbor pulp tissue and microbes after root canal treatment.[3]

Anatomical variations in mandibular first molar mesial root canals have been studied by micro-computed tomography (Micro-CT).[4] The reported incidence of isthmuses between two mandibular molar mesial canals ranges from 50% to 85% in the apical 5 mm, when using Micro-CT.[5,6] The filling quality of these canals has been studied for various obturation techniques.[7] Most root canal filling techniques employ a core material, which is most commonly gutta-percha,[1] and a sealer. However, gutta-percha placed by the traditional technique of cold lateral compaction (CLC), is inadequate for filling canal irregularities.[8] Therefore, heated gutta-percha techniques were developed, such as warm vertical compaction, thermo-plasticized injection, and continuous wave of condensation (CW), to better replicate irregular canal anatomy.[9] Additionally, root canal sealers are used to seal the space between gutta-percha and the canal wall, since gutta-percha does not adhere to dentin. However, most root canal sealers undergo dimensional changes after root canal obturation that compromises their seal.[10]

By contrast, a superior seal and enhanced biocompatibility can be obtained with mineral trioxide aggregate (MTA).[11] Although it was originally developed as a root-end filling material in surgical endodontics, MTA is now widely used for pulp capping, pulpotomy, and perforation repairs in nonsurgical treatment.[12,13] Furthermore, a hydroxyapatite-like interfacial layer forms at the MTA-dentin interface in the presence of phosphate buffered saline.[14] Orthograde MTA obturations showed less salivary leakage than gutta-percha with sealer in single root canals that had been prepared to an apical size 40/0.06.[15] OrthoMTA (BioMTA, Seoul, South Korea) is a kind of MTA developed specifically for orthograde root canal obturation. OrthoMTA contains less heavy metals than ProRoot MTA (Dentsply, Tulsa, OK, USA),[16] and has demonstrated intratubular mineralization following the obturation of single canals.[17,18]

Recently, Micro-CT has been used to obtain cross-sectional images of the obturated canals without damaging the teeth, and to calculate quantitative three-dimensional volumes for the root canal fillings.[19,20] These cross-sectional Micro-CT images correlate well with histological sections.[21] Therefore, the purpose of this study was to use Micro-CT to evaluate the filling quality of the apical 5 mm of the main canals and their isthmuses, in mandibular first molar mesial roots that were obturated by either CLC, CW, or OrthoMTA obturation (OMTA) in an orthograde manner.

Materials and methods

Sample selection and root canal preparation

Study approval was obtained from the Institutional Review Board of Seoul National University Dental Hospital (CRI 12006), Seoul, South Korea. Extracted human mandibular first molars were collected and stored in 10% neutral buffered formalin. Sixty teeth were selected with mesial roots with two separate canals extending from the pulp chamber to the apex, as confirmed on radiographs.

Endodontic access preparations were prepared with a No. 330 bur. Working lengths were established by inserting a No. 10 K-file into the mesiobuccal and mesiolingual canals, until the tip of the file was just visible at the apical foramen with a dental operating microscope (OPMI Pico, Carl Zeiss Surgical GmbH, Oberkochen, Germany). Prior to instrumentation, canal curvatures were viewed on radiographs taken from both buccal and mesial directions, with No. 15 K-files inserted into the mesiobuccal and mesiolingual canals.[22] Their curvatures (radius and degree) were measured with paint.NET software version 3.5 (dotPDN LLC, Kirkland, WA, USA). The teeth were then randomly divided into three groups of 20, so that there was an equitable distribution of canal curvature (radius and degree) between groups, as confirmed by one-way analysis of variance (Table 1).

The mesial root canals were cleaned and shaped with ProTaper Next Ni-Ti rotary files (Dentsply Maillefer, Ballaigues, Switzerland) according to the manufacturer's instructions, until the X4 file (apical size 40) reached working length. Between each instrumentation step, the canals were irrigated with 1 mL of 3.5% sodium hypochlorite (NaOCl) solution, delivered in a syringe with a 30-gauge needle (Max-i-Probe needle; Dentsply Rinn, Elgin, IL, USA). After instrumentation was completed, each canal was rinsed with 10 mL of 17% ethylenediaminetetraacetic acid (EDTA) to remove the smear layer, and then flushed with

Table 1 Buccal and proximal views of angle and radius of curved mesial root canals of three groups.

Group	Curvature (°)			Radius (mm)		
	Mean	SD	Range	Mean	SD	Range
Buccal view						
CLC	16.42	4.39	10.70–25.90	6.99	1.63	4.45–9.12
CW	16.41	3.84	10.60–25.70	7.24	1.62	5.02–9.35
OMTA	17.02	3.81	10.87–24.70	7.31	1.65	4.68–9.68
	$P = 0.745$			$P = 0.156$		
Proximal view						
CLC	14.22	3.36	10.10–32.0	7.26	1.93	4.04–9.98
CW	14.13	2.98	10.20–29.10	7.27	2.11	4.01–10.10
OMTA	14.57	3.43	10.70–28.60	7.48	2.08	4.09–9.95
	$P = 0.877$			$P = 0.694$		

CLC = cold lateral compaction; CW = continuous wave of condensation; OMTA = orthograde obturation using OrthoMTA; SD = standard deviation.

10 mL of 3.5% NaOCl.[23] Finally the canals were cleaned ultrasonically with 3.5% NaOCl by the PerioScan ultrasonic unit (Sirona Dental Systems, Bensheim, Germany) and its exclusive ultrasonic irrigation tip [Endospitze No. 5 tip (ISO 20): Sirona Dental Systems]. The ultrasonic tip was placed as far apically inside the canal as it would go without binding, and then moved up and down 2–3 mm for 30 seconds at low power, according to the manufacturer's instructions.

Root canal obturation

The prepared root canals were divided into three groups for obturation by three different techniques. In the first group (CLC, $n = 20$), a standardized 40/0.02 master cone (Meta Biomed, Cheongju, South Korea) was coated with AH Plus sealer (Dentsply, Johnson City, TN, USA) and placed to working length. A Ni–Ti Hyflex finger spreader size FM (Coltene/Whaledent, Mahwah, NJ, USA) was inserted to within 1–2 mm of working length and removed, and then a sealer-coated FM accessory cone (Meta Biomed) was placed.[24] Three to five accessory cones were inserted until the spreader no longer went beyond the coronal third of the canal.

In the second group (CW, $n = 20$), a standardized 40/0.06 gutta-percha cone (Diadent, Chungju, South Korea) was fitted and trimmed to obtain tug back at 1 mm short of working length, and then coated with AH Plus sealer. A B&L-alpha II tip (B&L Biotech, Ansan, South Korea) was heated to 200°C and inserted into the master cone until it was 4–5 mm from working length. Apical pressure was maintained without heat until the gutta-percha had cooled. Then, heat was reapplied to the B&L-alpha II tip for 1 second as it was retrieved, and the remaining gutta-percha was compacted with the cold S-Kondenser (Obtura Spartan, Fenton, MO, USA). The coronal portion of the canal was obturated with B&L-Beta (B&L Biotech) using regular type GP pellet (B&L Biotech), and vertically condensed with S-Kondensers.[9,25]

In the third group (OMTA, $n = 20$), an orthograde root canal filling was performed with OrthoMTA as previously described.[17,18] OrthoMTA was mixed with distilled water using the OrthoMTA automixer (BioMTA), as recommended by the manufacturer. The paste was introduced into the canal with the OrthoMTA carrier, and applied to the canal wall using the OrthoMTA compactor, which has a 25/0.02 tip. The compactor was inserted to working length and rotated with a circumferential filing motion at 60 rpm. After obtaining an apical stop, the S-Kondensor was used to compact the material.

All of the canal preparation and obturation techniques were performed by one endodontist (S. Oh.), to ensure consistency. Following their obturation the teeth were stored at 37°C with 100% humidity for 7 days to allow complete setting of sealer (CLC, CW) and OrthoMTA.

Micro-CT scan and image reconstruction

The obturated mesial roots were scanned by high-resolution Micro-CT (Skyscan 1172; Bruker-Micro-CT, Kontich, Belgium) at 100kV and 100μA using a 0.5 mm-thick aluminum filter and 30% beam hardening reduction, which had rotational steps of 0.5° and a cross-sectional pixel size of 14.87 μm. From these scans, cross-sectional images were reconstructed with NRecon software (version 1.6.9.18; Bruker-Micro-CT) to show two-dimensional slices of the internal root canal anatomy. Finally, three-dimensional models were created for volumetric analyses using CTAn (version 1.11.0.0; Bruker-Micro-CT) and CTVol software (version 2.1.1.2; Bruker-Micro-CT).

Canal areas that appeared to be filled with gutta-percha, sealer or OrthoMTA in the Micro-CT images were then verified by careful dissection and stereomicroscopic examination. The 3D volumes that were filled with gutta-percha, sealer, or OrthoMTA and the unfilled spaces of main canals or isthmuses in the apical 5 mm region were obtained by CTAn software (Bruker-Micro-CT). Filled volumes are the sum of gutta-percha and sealer occupied volumes in the CLC and CW obturated canals, and the OrthoMTA volumes in the OMTA group. Total root canal and total isthmus volumes in the apical 5 mm were obtained by summing the filled and unfilled volumes. Additionally, to assess adaptability of the filling material, the void volumes at the interface of the filling material and dentin were calculated

Table 2 Type of isthmuses and their total volumes (mean ± standard deviation) in the apical 5 mm of the canals.

Type of isthmus		CLC	CW	OMTA	Statistical differences
Incomplete Isthmuses	*n*	10	10	10	NS
	Volume (mm^3)	0.0691 ± 0.0392	0.0652 ± 0.0332	0.0645 ± 0.0312	NS
Complete Isthmuses	number	10	10	10	NS
	Volume (mm^3)	0.3098 ± 0.4531	0.3129 ± 0.2447	0.3227 ± 0.2662	NS

CLC = cold lateral compaction technique; CW = continuous wave of condensation technique; OMTA = orthograde obturation using OrthoMTA; NS = not significant; Volume = sum of filled and unfilled volume in each isthmus.

in the apical 5 mm of the main canals. The frequency of complete and incomplete isthmuses, and the mean total isthmus volumes were compared between groups using the Kruskal—Wallis test.

The filled volume ratio, and the gutta-percha and sealer volume ratios were calculated as a percentage of the main canal or isthmus volumes, for the apical 5 mm of the canals. The interface void volume ratio of the main canal was also calculated as a percentage of the main canal volume for the apical 5 mm. These datasets were tested for the assumption of normality and the equality of variance by Shapiro—Wilk and Levene tests. Since they were not normally distributed, the Kruskal—Wallis test was used to compare filled volume ratios and interface void volume ratios amongst groups in the main canals, and filled volume ratios within isthmuses. The Mann—Whitney *U* test was used to compare gutta-percha and sealer volume ratios between the CLC and CW groups in their main canals and isthmuses. Differences between the filled volume ratio in the main canals and isthmuses in each group were assessed by the Mann—Whitney *U* test. IBM SPSS version 21 software package (IBM Corp, Armonk, NY, USA) was used, and the level of significance was set at $P = 0.05$.

To evaluate the distribution of filling materials within the isthmuses, the ratio of filled isthmus area to total isthmus area on the Micro-CT cross-sections were calculated. The filled isthmus area was further identified as gutta-percha or sealer occupied areas in the CLC and CW obturated canals. Micro-CT cross-sections were examined at 0.1 mm intervals, from 0.5 mm to 5.0 mm from the working length in each root using CTAn software, and the total isthmus area was calculated from the sum of the filled and unfilled isthmus areas.

Results

There were no significant differences between the groups in the frequency of complete and incomplete isthmuses, and in mean total isthmus volumes (Table 2). In the main canals, there were no significant differences in the filled volume ratios, or gutta-percha and sealer volume ratios between groups (Table 3). However, the CLC canals showed significantly higher interface void volume ratios than the CW ($P = 0.001$), or OMTA ($P = 0.017$).

In the isthmuses, the filled volume ratio was significantly lower than that in the main canals for all groups ($P < 0.001$; Table 3). This was clearly visible in the 3D models obtained from Micro-CT (Figure 1). In isthmuses, the filled volume ratio in CLC canals was significantly lower than that in the CW ($P = 0.025$) or OMTA ($P = 0.002$). The gutta-percha volume ratio was also significantly lower in CLC than in CW ($P = 0.005$), but the sealer volume ratio was significantly higher in CLC than in CW ($P = 0.049$).

The area ratio of filling materials within isthmuses were calculated from Micro-CT cross-sections and plotted along the apical 5 mm length of the roots (Figure 2). The highest filled areas in CLC canals were at 0.5—0.6 mm and 4.6—4.7 mm from the apex, which coincided with the highest sealer occupied areas. The highest filled areas in the CW canals were at 4—5 mm, and these decreased gradually towards the apex. The highest filled areas in the

Table 3 Filled and void volumes in the main canals and isthmuses in the apical 5 mm of obturated canals.

Volume (%)		Group		
		CLC	CW	OMTA
Main canal	Filled volume	$99.22 \pm 0.21^{a,B}$	$99.72 \pm 0.13^{a,B}$	$99.79 \pm 0.38^{a,B}$
	Gutta-percha volume	91.70 ± 4.75^{a}	93.13 ± 4.29^{a}	N/A
	Sealer volume	8.04 ± 4.76^{a}	6.55 ± 4.27^{a}	N/A
	Interface void volume	0.77 ± 0.16^{b}	0.27 ± 0.12^{a}	0.19 ± 0.19^{a}
Isthmus	Filled volume	$61.15 \pm 12.46^{a,A}$	$80.11 \pm 12.99^{b,A}$	$82.98 \pm 9.75^{b,A}$
	Gutta-percha volume	43.26 ± 14.32^{a}	71.03 ± 12.68^{b}	N/A
	Sealer volume	17.88 ± 12.05^{b}	9.07 ± 6.03^{a}	N/A

Same superscript lowercase letters in each row indicate no significant differences between obturation techniques ($P > 0.05$). Different superscript uppercase letters in each column indicate a significant difference in filled volume ratio between main canal and isthmus ($P < 0.001$).

CLC = cold lateral compaction technique; CW = continuous wave of condensation technique; OMTA = orthograde obturation using Ortho MTA; N/A = not applicable.

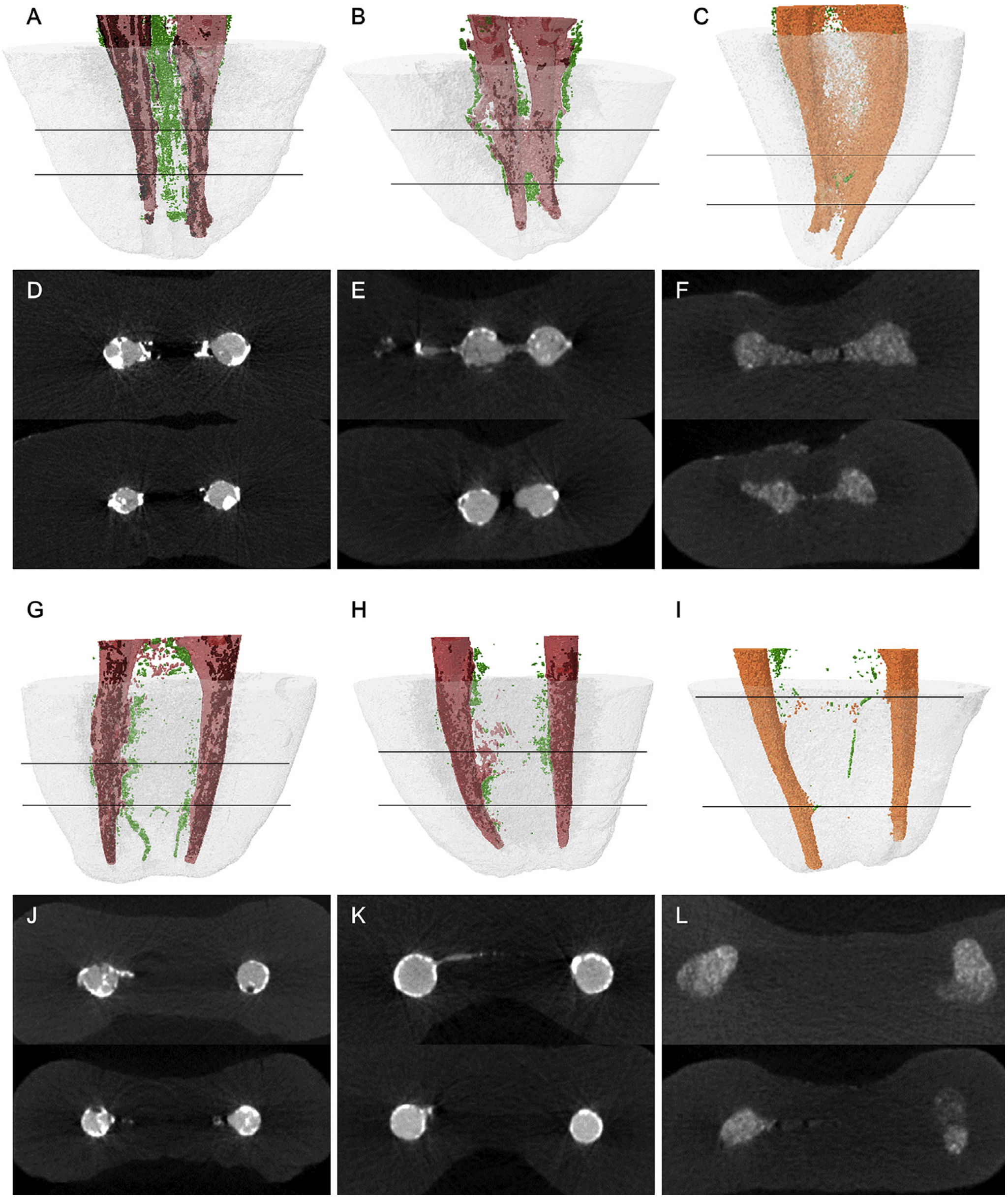

Figure 1 Micro-computed tomographic images of obturated mandibular first molar mesial root canals with (A—F) complete isthmuses or (G—L) incomplete isthmuses. (A—C, G—I) Reconstructed 3D images of filled roots with gutta-percha (red), sealer (black), OMTA (orange), and unfilled canal space (green). (D—F, J—L) Cross-sectional images at the level of the solid lines (black) (A—C, G—I). (D) 2.0 mm, 3.2 mm; (E) 1.7 mm, 3.3 mm; (F) 1.2 mm, 2.9 mm; (J) 2.0 mm, 3.4 mm; (K) 2.1 mm, 3.8 mm; (L) 1.6 mm, 4.8 mm levels from the working length. (A, D, G, J) Group CLC. (B, E, H, K) Group CW. (C, F, I, L) Group OMTA. CLC = cold lateral compaction technique; CW = continuous wave of condensation technique; OMTA = orthograde MTA obturation using OrthoMTA.

OMTA were at 0.5—1 mm near the apex, and they remained relatively high towards the coronal.

Discussion

This study used high-resolution Micro-CT to compare three techniques for obturating the apical 5 mm of mandibular first molar mesial root canals. The apical 5 mm region was chosen for analysis, since the apical 3—5 mm has been reported to have the highest prevalence of isthmuses.[5,26] The mesial root canals were prepared to an apical size of 40, to allow adequate volume and exchange of root canal irrigant,[27] and effective disinfection of root canals without impairing remaining dentin thickness.[28]

The Micro-CT images were effective in distinguishing the filling materials, gutta-percha, sealer, and OrthoMTA, from the surrounding root canal dentin walls and void spaces, as shown in prior studies.[19—21] All of the roots showed almost complete filling of the canal space ($> 99\%$) with minimal ($< 1\%$) voids in the main canals, regardless of the obturation technique. When sealer was used (CLC, CW), it filled around 6—8% of the total volume in the main canals, and did not show any significant difference between groups.

However, the main canals obturated by CLC had less well adapted fillings with significantly more ($P < 0.05$) interfacial void volume than those obturated by CW or OMTA. There were straight linear voids at the interface between the gutta-percha and dentin in the CLC group. These voids were attributed to spreader tracts that had been shown in a previous study,[24] and would become passageways for bacterial leakage and cause endodontic failure.[29] In contrast to the main canals, the isthmuses were incompletely filled (60–85%). These intricate canal anatomies were better filled by the warm gutta-percha technique of CW than by CLC, as previously reported.[8,30] There was significantly more gutta-percha filled volume in the CW filled isthmuses than the CLC filled isthmuses ($P < 0.05$). Nonetheless, cross-sectional Micro-CT analyses of the CW filled isthmuses showed that there was a progressive decrease in gutta-percha density towards the apex, which may have been due to insufficient softening of gutta-percha near the apex.

The incomplete filling of isthmuses was at least partially due to the presence of pulp tissue remnants and hard tissue debris. A previous Micro-CT study found dentin debris packed into the isthmus areas of mandibular molar mesial roots that had been irrigated with side-vented 30-gauge needles during canal preparation.[31] They also found that there was much less filling of the isthmus volume (57.5%) compared to the main canals (98.5%).[31] Another Micro-CT study found that a third of the isthmus volume contained hard tissue debris, when mandibular molar mesial root canals had been prepared without irrigation.[32] Therefore this study used passive ultrasonic irrigation to reduce hard tissue debris and the smear layer. Nevertheless some debris remained, as shown in prior studies using the same ultrasonic irrigation to reduce isthmus debris.[33,34] Ricucci and Siqueira[35] indicated that lateral canals appeared radiographically filled—they were actually not obturated—and the remaining tissue in the ramification was inflamed and enmeshed with the filling material. Effective disinfection of isthmus is more crucial element than obturation in successful root canal treatment.

In this study, the final rinse used 17% EDTA followed by NaOCl, since it is the recommended combination to remove smear layer.[23] However, other studies have indicated that the use of NaOCl after EDTA irrigation can induce excessive erosion of root canal dentin.[36,37] Therefore we carefully limited the final NaOCl irrigation time to 1 minute to minimize the erosion of dentin.

Even when filling materials adequately fill canals, gutta-percha does not chemically bond to dentin, whereas MTA can form an interfacial layer.[14,17,18] This interfacial layer of tag-like structures contains calcium and phosphorus, which optimize the sealing ability of MTA-filled root canals. Furthermore, intratubular mineralization following orthograde OrthoMTA obturation resulted in bacterial entombment in the dentinal tubules of experimentally infected root canals.[17] The manufacturer claims that OrthoMTA can penetrate into dentinal tubules attributing to its small particle size.[38]

In this study, three-dimensional root canal obturations with OrthoMTA were observed by Micro-CT. Similarly, a prior study showed that root canals filled with MTA could be identified by Micro-CT.[20] Direct contact between OrthoMTA

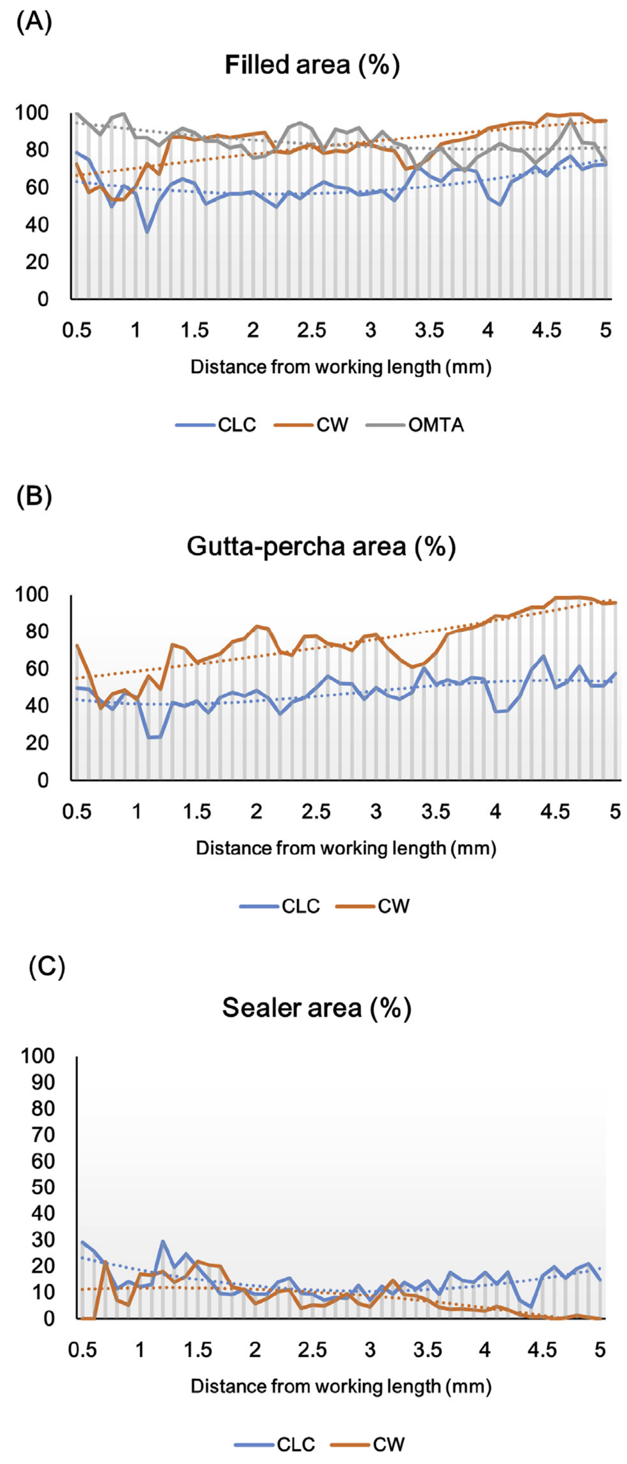

Figure 2 Distribution of filling materials within isthmuses in cross-sectional micro-computed tomographic images. Surface areas (%; solid lines) occupied by (A) filling; (B) gutta-percha; and (C) sealer, and their trend (dotted lines) for three groups, at increasing distance from the working length (mm). CLC = cold lateral compaction technique; CW = continuous wave of condensation technique; OMTA = orthograde MTA obturation using OrthoMTA.

and root canal dentin was seen in this study, although uneven densities in the images may have been due to variations in mineral components and the inherent porosity of the material. Macro- and microporosities of hydrated MTA can be caused by inadequate water-to-powder ratio, insufficient packing or water evaporation,[20,39,40] which can lead to leakage of the filling. Furthermore, MTA has a prolonged setting time, can cause tooth discoloration, and is hard to retrieve for retreatment.[13] Therefore, orthograde MTA obturations need to be limited to carefully selected cases.[12] Whereas adequate root canal obturation could be attained with limited debridement, orthograde obturation using OrthoMTA should be performed after thorough cleaning and shaping. Accordingly, the apical enlargement to No. 40 promoted the delivery of irrigants and facilitated the application of OrthoMTA to working length.[18,27]

Within the limitations of this study, orthograde MTA obturation showed comparable filling quality to gutta-percha with sealer. Filling adaptation to the canal walls and filling density within isthmuses were inferior in the cold lateral compaction filled canals, compared to the continuous wave of condensation or orthograde MTA.

Conflicts of interest

The authors have no conflicts of interest relevant to this article.

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