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Original

Micro-CT assessment of the sealing ability of three root canal filling techniques

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Abstract: This study used micro-CT to compare three obturation techniques with respect to void occurrence in canals filled with bioceramic sealer. Thirty extracted first mandibular premolars were prepared with a ProTaper Universal system and randomly allocated to three groups. Canals were obturated with gutta-percha and bioceramic root canal sealer, using either single-cone, lateral compaction, or Thermafil filling technique. Each tooth was then scanned with micro-CT. Voids in 2D cross-sectional images and void volumes in 3D images of all root thirds were assessed in relation to obturation technique. There was no significant difference between obturation techniques in the proportion of sections with voids ($P > 0.05$). However, the results of the obturation techniques significantly differed in relation to root region ($P < 0.05$). In conclusion, no root filling technique resulted in void-free specimens. Void volumes were highest for the single-cone technique and lowest for Thermafil, in all regions ($P < 0.05$). (J Oral Sci 57, 361-366, 2015)

Keywords: bioceramic sealer; micro-CT; obturation techniques; voids.

Introduction

The optimal endodontic treatment removes microorganisms and obturates the root canal in order to produce a fluid-tight seal (1). A hermetic seal is crucial for successful root canal treatment, which should attempt to eradicate as many microorganisms as possible, in order to leave no voids for bacteria to populate and proliferate (2).

Current obturation techniques include warm vertical compaction cold lateral compaction single-cone, and core-carrier (Thermafil) techniques. The single-cone technique is often used because of its improved adaptation to the dentinal wall (3). An advantage of this technique is shorter treatment time as compared with lateral compaction (4). Lateral compaction is the standard procedure for evaluating other obturation techniques and is more commonly used than the other obturation techniques (5). However, cold lateral compaction is time-consuming and may induce microcracks in the root, due to pressure applied during compaction of the material. The core-carrier technique improves adaptation of gutta-percha and the spread of obturators into accessory canals. However, retreatment and preparation of post spaces

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can be more challenging as compared with other filling techniques (6).

Various sealers are now available for use in endodontic treatment. Calcium silicate-based bioceramic root canal sealers are being introduced to endodontics. They are injectable, premixed, radiopaque, zero-shrinkage, insoluble, hydrophilic, and aluminum-free (7). Several techniques may be used to evaluate the quality of root canal fillings, such as radiographic visualization and computed tomography (CT) images (8-10). Recently, micro-CT (μ-CT) imaging has been used to scan and reconstruct three-dimensional (3D) images that allow accurate assessment of root filling outcomes (2,11).

We used μ-CT to compare three root canal filling techniques (single cone, lateral compaction, Thermafil) with respect to void occurrence after procedures using a bioceramic sealer. The null hypothesis was that Thermafil obturation would result in fewer voids when a bioceramic sealer was used.

Materials and Methods

Thirty extracted first mandibular premolars were included in the study. The protocol of the current study was in line with Declaration of Helsinki, including all amendments and revisions (approval no. 87307621-622, 2015). The consent forms were signed by the patients or the legal delegates of the patients. The patients provided consent to researchers to publish photos, radiographs, and other images of their teeth. The teeth were single-rooted and had a single straight canal and no caries, resorption, or fractures. A Gracey curette was used to remove soft tissue and calculus. The teeth were disinfected in 5.25% NaOCl for 2 h, after which they were stored in distilled water until the experiment.

Conventional radiography was used to examine tooth morphology. All tooth crowns were cut from the cemento-enamel junction to ensure a length of approximately 12 mm. An operating microscope was used to observe the teeth from the coronal surface, and only teeth with round canals were included in the standardization procedure before the experiment. Then, a #10 K-File (Dentsply-Maillefer; Tulsa, OK, USA) was placed in the root canal until it could be seen in the apex. The working length was then determined by deducting 0.5 mm from this length.

The roots were instrumented with ProTaper Universal files (Dentsply-Maillefer; Ballaigues, Switzerland) to F3 by an endodontist with 5 years of experience (BC). An X-Smart electronic motor (Dentsply-Maillefer) was used at 250 rpm. The files were used according to the manufacturers' recommendations, as follows: S1, S2, F1, F2, and F3. Two milliliters of 2.5% NaOCl was used for irrigation between instrumentations. Final irrigation was done with 2 mL NaOCl and 17% EDTA for 1 min, followed by 5 mL distilled water. The canals were then dried with paper points (Gapadent Co, Ltd; Tianjin, China).

Root canal filling

Three experimental groups were studied (10 roots in each group). The roots were obturated with single-cone (SC), lateral compaction (LC), or Thermafil technique. EndoSequence BC Sealer (Brasseler USA; Savannah, GA, USA) was used with all three obturation techniques, according to the manufacturer's recommendations. First, a lentulo spiral (size 25) was placed in the canal by a single operator, which was fit at 2 mm from the biomechanical preparation and removed slowly and continuously with a rotation of 300 rpm and 1 N cm of torque. A random selection process (drawing of lots) was used to allocate roots to the treatment groups.

Group 1 was obturated with SC (sealer and F3 gutta-percha). Gutta-percha protruding coronally from the roots was detached using a heat instrument and then the remaining material was vertically compacted with a hand plugger.

Group 2 was obturated with LC technique. A size 30 gutta-percha cone with a taper of 0.02 (Roeko; Langenau, Germany) was placed in the root canal, using apical tug-back sensation. A lateral compaction master cone (#30, taper 0.02) was then used with a size 15 spreader. Additional gutta-percha cones were placed until the material was 3 mm apical of the canal orifice. Excessive gutta-percha protruding coronally from roots was detached using a heat instrument and then the remaining material was vertically compacted with a hand plugger.

Group 3 was obturated with Thermafil technique. A Thermafil obturator of the same size as a #30 verifier was fit passively at working length with an adjustable rubber stop. The obturator was prepared in a Soft-Core DT oven (CMS Dental; Copenhagen, Denmark). After this procedure, the obturator was placed slowly with no movement. When the Thermafil cone had cooled, the obturator was cut at the canal orifice. After obturation, roots were kept at 37°C and 100% humidity to confirm that the filling materials had set.

μ-CT investigation

All roots were scanned with a μ-CT system (Bruker Skyscan 1172; Kontich, Belgium). The parameters were 100 kVp, 100 mA, 13.47 μm pixel size, and beam hardening correction of 40%. The detector was calibrated before all scans, to minimize ring artifacts. Rotation for

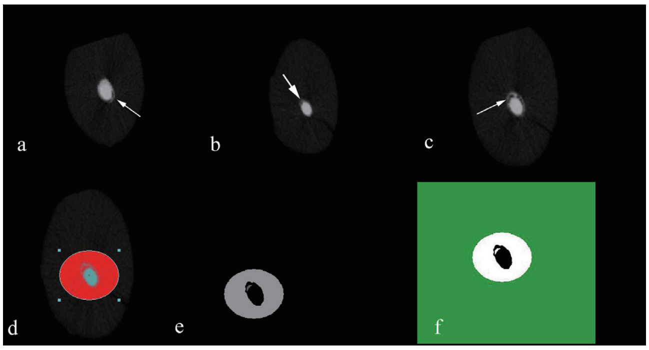

Fig. 1 μ-CT sections showing an (a) internal void, (b) external void, (c) combined void, (d) ROI selection on an image, (e) void inside an ROI, and a (f) gray-level histogram adjustment for image binarization.

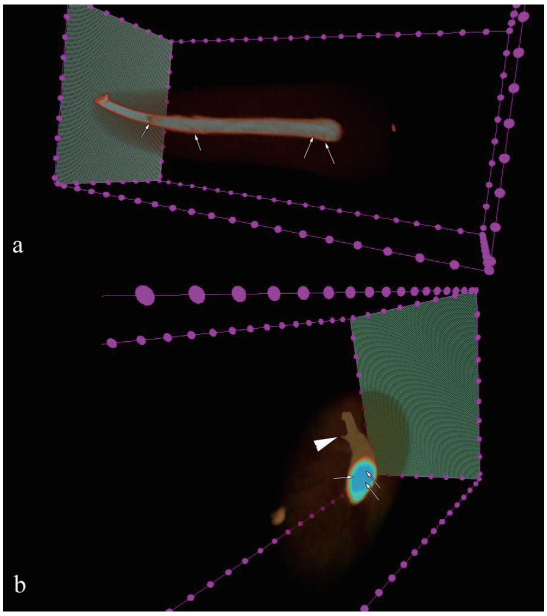

Fig. 2 (a) Three-dimensional representation of the root, voids (arrows), gutta-percha, and sealer (long arrows). (b) The lateral accessory canal in this root was obturated using the Thermafil technique.

all samples was 360°, with a 5-min integration time. The approximate scanning time was 2 h.

μ-CT analysis

NRecon (Bruker SkyScan; Kontich, Belgium) and CTAn software were used for evaluation and void measurements. A previously described modified algorithm (12) was used to collect axial 2D (1,000 × 1,000 pixel) images. Ring artifact correction and smoothing were set to zero, with a beam hardening correction of 40%. The manufacturer's recommended limits for contrast were used. First, the images were reconstructed to show 2D slices, from which 1,023 cross-sectional images were reconstructed. In addition, CTAn software was used for 3D volumetric visualization, analysis, and determination of the volume of the root canal measurement.

The presence of voids was determined in 2D slices viewed on a thin-film transistor (TFT) medical monitor, using a recently reported study protocol (13). In total, 256 cross-sectional TIFF images (interval, 0.5 mm) from the apical to coronal regions of the root were prepared as new cross-sectional images. All images were examined by a single evaluator (KO), who was allowed to use magnification and specification of the software. The evaluator was blinded to data regarding the root filling technique.

The volumes were investigated after image processing using the original grayscale Gaussian low-pass filter. An automatic segmentation procedure was performed to deduct dentin from sealer, gutta-percha, and voids, using the same software. A binarization process was then performed, which required processing gray level ranges to constitute imposed monochrome images (Fig. 1). A region of interest (ROI) comprising the entire object was selected for calculation of void volumes. The roots were separated for evaluation of voids, as follows: 0-4 mm (apical), 4-8 mm (middle), and 8-12 mm (coronal).

μ-CT was used to calculate the root filling volume percentages (sum of the volumes of the gutta-percha and endodontic sealer), the volume of internal voids distributed inside the filling material (between gutta-percha and sealer), the volume of external voids along canal walls (between the sealer and gutta-percha), and the volume of combined voids in materials communicating with the canal walls (Fig. 2).

Statistical analysis

Correlations between groups were tested using the Mann-Whitney *U*-test. The Kruskal-Wallis H-test with Bonferroni correction was used to assess differences between groups. SPSS software (ver. 20; Chicago, IL, USA) was used for all analyses. A P value of less than 0.05 was considered to indicate statistical significance.

Results

Table 1 shows the proportions of sections with voids in 2D slices and 3D volumes, by obturation technique. No significant differences were found with respect to proportions of sections with voids in 2D slices. There were no differences in relation to filling material volume or voids. The obturation techniques had comparable filling characteristics ($P > 0.05$).

Table 2 shows the mean percentages (SD) of root canal filling voids in 3D volumes, by obturation technique, in

Table 1 Mean (SD) percentages of sections with voids in 2D slices and 3D volumes, by obturation technique

Obturation techniques	n	Mean (range)	SD	Kruskal Wallis H Test	
				P	Pairwise comparison
Proportions of section with voids (%)					
Single cone	10	65.5 (28.2-100)	22.8	0.186	$P > 0.05$
Lateral compaction	10	53.2 (24.2-100)	26.3		
Thermafil	10	46.6 (20.4-100)	17.9		
Total	30	57.8 (24.2-100)	22.5		
Root Filling (%) Gutta-percha + Sealer					
Single cone	10	97.8	1.2	0.542	$P > 0.05$
Lateral compaction	10	98.1	1.3		
Thermafil	10	98.3	1.3		
Total	30	98.1	1.3		
Internal voids (%)					
Single cone	10	0.5	0.2	0.710	$P > 0.05$
Lateral compaction	10	0.5	0.2		
Thermafil	10	0.4	0.2		
Total	30	0.5	0.2		
External voids (%)					
Single cone	10	0.9	0.6	0.837	$P > 0.05$
Lateral compaction	10	0.8	0.5		
Thermafil	10	0.7	0.4		
Total	30	0.8	0.5		
Combined voids (%)					
Single cone	10	0.7	0.4	0.745	$P > 0.05$
Lateral compaction	10	0.6	0.3		
Thermafil	10	0.6	0.3		
Total	30	0.6	0.4		

Table 2 Mean (SD) percentages of root canal filling voids in 3D volumes by obturation technique in the apical, middle, and coronal thirds

Regions	Obturation techniques	n	Mean	SD	P value	Pairwise comparisons
Apical	Single cone	10	0.6	0.2		
	Lateral compaction	10	0.5	0.2	$P < 0.05$*	1-3 2-3
	Thermafil	10	0.3	0.1		
Middle	Single cone	10	1.5	0.5		
	Lateral compaction	10	1.3	0.4	$P < 0.05$*	1-2 1-3
	Thermafil	10	1.1	0.4		
Coronal	Single cone	10	2.1	0.8		
	Lateral compaction	10	1.9	0.7	$P < 0.05$*	1-2 1-3
	Thermafil	10	1.6	0.6		
Overall total		30	1.2	0.4		

*statistically significant

the apical, middle, and coronal thirds. There were significantly fewer voids in the apical third than in the coronal third ($P < 0.05$). The SC technique had the largest void volumes, and Thermafil the smallest void volumes, at all levels ($P < 0.05$). In pairwise comparisons, the SC, Thermafil, and LC techniques significantly differed ($P < 0.05$) at the apical level. However, there was no significant difference between the LC and Thermafil techniques at the middle or coronal levels ($P > 0.05$).

Discussion

Successful endodontic treatment requires removal of microorganisms by means of effective preparation, disinfection, and obturation of the root canal (14). Root canal filling is a crucial step in successful endodontic treatment (15). Because of the complex and varying anatomy of teeth, removal of microorganisms is not always possible. Accessory canals, irregularities, and isthmuses may lead to insufficient preparation and irrigation and incomplete removal of microorganisms (16). For successful treatment, surviving microorganisms must be sealed with an appropriate root filling, which should block microorganisms and toxins from entering the root canal system from the oral cavity (17).

The quality of root canal fillings is therefore essential for successful root canal treatment. Several methods are used to evaluate root canal quality, and dyes or alternative tracers are generally used for this purpose (18). However, reports suggest that these conventional methods have disadvantages, the most common of which are the considerable time required and lack of standardization (19-21). In addition, dye penetration cannot adequately simulate true clinical conditions, which are characterized by hindrance of fluid movement due to air entrapment in voids along the root canal filling (21).

In recent years, μ-CT analysis is increasingly used for noninvasive assessment of objective variables. Volumes can be calculated and, moreover, qualitative visual image analysis can be performed with this technique. μ-CT has the potential to differentiate filling materials, voids, and tooth structures (11).

Several studies have evaluated root canal filling quality for various obturation techniques, using scanning electron microscopy, μ-CT, and confocal laser scanning microscopy (13,22-26). Marciano et al. (22) used confocal laser scanning microscopy to compare four techniques (SC, LC, system B, Thermafil). Voids were similar for LC and SC at the 2-mm apical level. Moreover, Thermafil resulted in fewer voids and less sealer, as compared with SC, at the 2- and 4-mm levels. Overall, Thermafil required significantly less sealer and resulted in significantly fewer voids at all levels, as compared with the other techniques (22). These results were confirmed in the present study: Thermafil had the lowest void volumes at all levels (the apical, middle, and coronal thirds).

Somma et al. (23) used μ-CT to evaluate sealing of root fillings *ex vivo* using Thermafil and system B and SC technique. The mean percentages of filling materials were 98.4% ± 1.2% in the SC group and 99.0% ± 1.4% in the Thermafil group. In our study, the mean percentages of filling materials were 97.8% ± 1.2% in the SC technique and 98.3% ± 1.3% in the Thermafil group. No significant difference was found among the groups, which is consistent with the findings of Somma et al. (23). Our findings showed better adaptation and fewer voids with the Thermafil technique in combination with the tested bioceramic sealer.

LC can lead to partial adaptation of gutta-percha cones, surface adaptation irregularities, and sealer shrinkage, with resulting voids in root canal fillings. In contrast, the Thermafil technique achieves better adaptation to canal walls and fewer voids, as it utilizes a homogeneous mass and heat-softened cones (24,25).

Keleş et al. (25) used μ-CT to evaluate voids after LC and warm compaction. As compared with LC, warm vertical compaction resulted in significantly greater gutta-percha volume and a lower percentage of voids. Naseri et al. (24) used μ-CT to compare the sealing ability of four canal filling techniques—LC technique, warm vertical condensation, Obtura II, and Gutta Flow. All the techniques resulted in voids. In a μ-CT study by Moeller et al. (13), voids were frequent from the apical to the cervical regions after using the LC and hybrid techniques with AH Plus sealer.

Li et al. (26) used μ-CT to investigate three obturation techniques used in conjunction with ThermaSeal Plus sealer. The roots were divided into three regions (0-4, 4-8, and 8-12 mm). They found that canals obturated with GuttaCore carriers had the lowest incidence of interfacial gaps and voids, although the difference in relation to warm vertical compaction was not significant. As was the case in previous studies (27,28), our results suggest that SC technique, which does not use compaction forces, results in voids due to the presence of irregularly shaped canals.

We found no statistical difference in relation to obturation techniques with respect to the proportion of μ-CT sections with voids. Moreover, there were no significant differences with respect to filling material volume percentages and voids. However, the results for the obturation techniques significantly differed by root region. We noted a noticeable reduction in combined voids in the apical third and a significant difference between the apical and coronal thirds of roots.

This study used a single sealer, which could be considered a study limitation. Future experiments should compare obturation techniques used in combination with various root canal sealers.

In summary, voids were present for all root filling obturation techniques. At all levels, void volumes were highest for the SC technique and lowest for Thermafil, with the tested bioceramic sealer. The null hypothesis was thus accepted, as the bioceramic root canal filling material effectively filled root canals, with similar void characteristics, when used with different obturation techniques.

Conflict of interest
The authors have no conflict of interest to declare.

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