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Original article

Use of micro-CT to examine effects of heat on coronal obturation

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(Received January 14, 2022; Accepted April 22, 2022)

Abstract

Purpose: The aim of this study was to categorize the effects of heat on coronal obturation with gutta-percha and sealer using X-ray micro-computed tomography (micro-CT).

Methods: Ten single-rooted, extracted human teeth were shaped using ProTaper NEXT files to size X5 (#50/Taper 6%) with 2.5% NaOCl irrigation. A single ProTaper NEXT X5 gutta-percha point was then inserted with epoxy resin (AH Plus) or tricalcium silicate (EndoSequence BC) sealer ($n = 5/\text{group}$), and cut at the cemento-enamel junction. The teeth were scanned using micro-CT (SkyScan1272) to obtain 11 sagittal 2-D images. Three calibrated raters categorized the coronal 0.5 mm of the images into four categories: “swirled sealer and/or gutta-percha without voids” (I), “uniform voids and sealer/gutta-percha” (II), “non-uniform voids and sealer/gutta-percha” (III), and “swirled sealer and/or gutta-percha with voids” (IV). Intra-rater and inter-rater reliability were then calculated. Chi-square tests were conducted to determine the significance of differences in each category between sealers.

Results: The intra-class correlation coefficient was 0.55 (same rater/two different times) and Fleiss’ kappa (different raters/same image) was 0.34. Categories I, II, III, and IV accounted for 16.4%, 4.2%, 30.3%, and 49.1% for AH Plus, and 6.7%, 4.2%, 27.3%, and 61.8% for EndoSequence BC, respectively.

Conclusion: Category IV was most common and Category II the least common. Significant differences were evident between sealers for Category I ($P < 0.01$).

Keywords: endodontic sealers, epoxy resin, heat, micro-CT, tricalcium silicate

Introduction

Endodontic obturation without voids in the coronal area is associated with improved clinical outcomes of non-surgical root canal treatment (NSRCT) [1,2]. Voids in the coronal area are created as a result of heat, the method of sealer application, and the rheological properties of the sealers [3,4]. Therefore, a sealer that adapts well to dentin can better ensure void-free obturation and prevent coronal microleakage [1,5,6].

Several obturation techniques are available to endodontic specialists and general dentists; the most common are cold lateral, single-cone, warm vertical, and carrier-based [7,8]. Warm vertical obturation is preferred by endodontic residents in the United States, followed by single-cone obturation [7], whereas general dentists in North America prefer the single-cone technique [8]. The cold lateral and warm vertical techniques were developed for use with zinc oxide-eugenol or epoxy resin sealers, whereas the single-cone technique was popularized for early tricalcium silicate-based sealers [9-12]. All obturation techniques require heated devices for coronal compaction; examples of such equipment include the Calamus Pack heat

carrier system (Dentsply Sirona, Charlotte, NC, USA) [13] and System B (Analytic Technology, Redmond, WA, USA) [14]. Heat can affect the integrity of both gutta-percha and sealers in the coronal area.

Although the impact of heat application on the coronal area has been studied [15], further investigations are needed to clarify how heat causes gutta-percha to intermingle with a sealer. Furthermore, heat can affect the integrity of gutta-percha and sealers by evaporating or decomposing some sealer components. Previous research [16-18] has indicated that heat application during obturation induces changes that are related to the properties of the sealer. For example, a recent study [19] of the effect of heat on an AH Plus sealer revealed only a minimal alteration of the melting point. Another study [20] that involved heating epoxy resin and tricalcium silicate sealers to 100°C revealed significant decreases in setting time and flow. Therefore, the heat generated from endodontic obturation techniques may impact the sealing of some endodontic sealers [19]. Therefore, to improve the efficacy of sealing, more investigations are needed to determine how heat causes gutta-percha to melt and interact with different sealers.

Although the effects of heat have been discussed independently [15-20], no previous studies have focused on gutta-percha and sealer interactions and any resulting microscopic voids when heat is applied. Two-dimensional techniques [21,22] such as scanning electron microscopy (SEM) require sample destruction, which can distort the nature of gutta-percha/sealer interactions. High-resolution X-ray micro-computed tomography (micro-CT) is a relatively new non-destructive three-dimensional (3-D) imaging technique that can provide *in situ* observations of gutta-percha and sealer distributions at the microscopic level [13].

The aim of the present study was to categorize and compare the effects of heat on coronal obturation with gutta-percha and epoxy resin or tricalcium silicate materials using micro-CT *in vitro*.

Materials and Methods

Materials

Two endodontic sealers, described in Table 1 with their compositions, working time, setting time, and radiopacity, were used [4,10,23-27]. These sealers are the most commonly used epoxy resin and tricalcium silicate products, although not the only ones with epoxy or tricalcium silicate matrices. Both sealers have working and setting times exceeding 2 h; however, the tricalcium silicate paste requires a wet environment to set, unlike the self-setting two-part epoxy resin.

Extracted human teeth

The University of New England Ethics Committee provided approval (Institutional Review Board: # 010617-005, Not Human Subject Research) for this study to use permanent, human, single-rooted, maxillary, anterior teeth. Preoperative digital radiographs were taken (Schick 33 Intraoral sensor, Dentsply Sirona) to exclude teeth with multiple canals, cracks, fractures, resorption, caries, immature apices, or a root curvature of more than 10°. Ten teeth were selected and divided into two groups ($n = 5$).

Root canal preparation

Access to the root canal was gained using a bur, and a size 10 K-file (Dentsply Sirona) was then used to establish a 15-mm working length (1 mm short of the apical foramen). A #10 K-file was used to extend the working length 1 mm beyond the anatomical apex to verify canal patency. Canals were cleaned and shaped with ProTaper NEXT NiTi rotary files

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Color figures can be viewed in the online issue at J-STAGE.
doi.org/10.2334/josnusd.22-0013
DN/JST.JSTAGE/josnusd/22-0013

Table 1 Endodontic sealers evaluated

Chemical matrix	Product name (Manufacturer, City, Country)	Component	Composition	Lot #	Working time (h)	Setting time (h)	Radiopacity (mm Al)
Epoxy resin	AH Plus (Dentsply Sirona, Charlotte, NC, USA)	Paste A	bisphenol A epoxy resin, zirconia, bisphenol F epoxy resin, calcium tungstate, iron oxide, silica	119047	4	8.3	10.0
		Paste B	<i>N,N</i> -dibenzyl-5-oxanonadiamin-1,9, amantiamine, tricyclodecane-diamine, calcium tungstate, zirconia				
Tricalcium silicate	EndoSequence BC (Brasseler, Savannah, GA, USA)	Single paste	zirconia, calcium silicate cement, calcium phosphate, calcium hydroxide, filler, thickening agents	16002SP	>24	2.7, 6.7, 25*	6.7

*In a water bath or otherwise moist at 37°C [10,26,27]

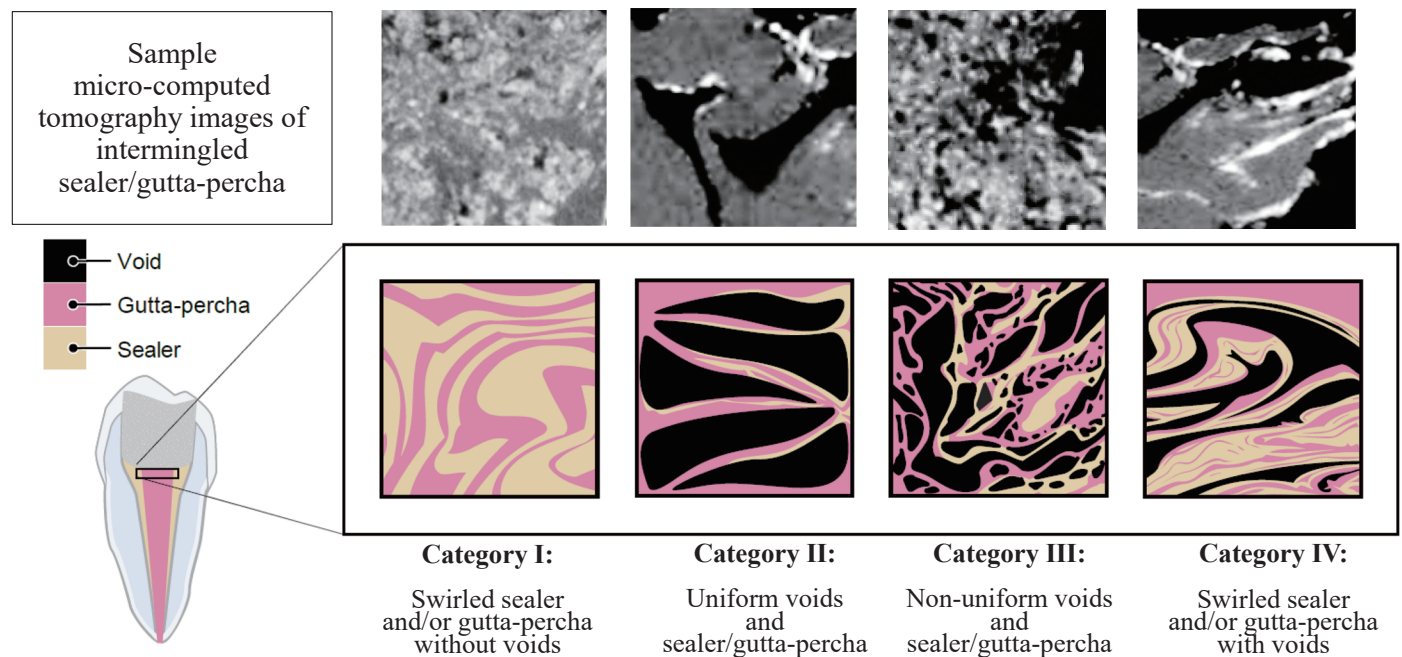


Fig. 1 Sample micro-computed tomography images of intermingled sealer/gutta-percha and schema of 4 categories of endodontic obturation in the coronal area

(Dentsply Sirona) using five instruments, X1 to X5 (#50/variable taper, a 6% taper with a 3 mm tip), successively with a ProMark torque-limited electric motor (Dentsply Sirona). Canals were irrigated at each instrument change with 2 mL of 2.5% sodium hypochlorite (NaOCl) through a 27-G needle (Ultradent Inc., South Jordan, UT, USA). After irrigation with 5 mL of 17% EDTA for one minute, followed by 5 mL of 2.5% NaOCl, the canals were dried with ProTaper NEXT absorbent points (Dentsply Sirona).

Single-cone root canal filling with a gutta-percha point and sealer

Each root was fitted with a size X5 ProTaper NEXT, variable-taper gutta-percha point (Dentsply Sirona). Next, AH Plus (Dentsply Sirona) or EndoSequence BC (Brasseler, Savannah, GA, USA) was used to obturate each root. The AH Plus sealer required mixing of two pastes; the single paste EndoSequence BC sealer did not require preparation. A gutta-percha point was buttered for the AH Plus before placement, and inserted into the canal to the working length. The dispensing tip was used to place the EndoSequence BC sealer into the apical area of the canal before the gutta-percha point was inserted. With both sealers, a heated Calamus Pack heat carrier system (Dentsply Sirona) was used to cut and vertically condense the warm gutta-percha with an endodontic plugger. Only the coronal area of each tooth was affected by the heat. The obturated teeth were stored for 30 h at 37°C in phosphate-buffered saline (PBS) (VWR, Radnor, PA, USA) to ensure complete setting of the sealers.

μCT scanning and image analysis of coronal sealer/gutta-percha

Each tooth was scanned using X-ray micro-computed tomography (Sky-Scan1272, Bruker, Billerica, MA, USA) at 6 μm voxel size, 90 kVp, 110 μA, with 0.5-mm aluminum and 0.038-mm copper filters. All datasets were exported in a digital imaging and communications in medicine (DICOM)

file format.

The reconstructed 3-D image of each tooth was rotated around its central axis, and sagittal images were captured for analysis at each 30° for a total of 11 images per tooth using 3-D image analysis software (Dragonfly, Object Research Systems, Montreal, Canada). For the 10 teeth, 110 high-resolution images (55 images for each sealer group) were saved for the analysis. Only the coronal 0.5 mm was examined.

Definition of four categories of intermingled coronal sealer/gutta-percha images

Four patterns were identified as categories to ensure objective and systematic examination. Figure 1 shows sample micro-computed tomography images of coronal sealer/gutta-percha and a schema of the four categories: “swirled sealer and/or gutta-percha without voids” (Category I), “uniform voids and sealer/gutta-percha” (Category II), “non-uniform voids and sealer/gutta-percha” (Category III), and “swirled sealer and/or gutta-percha with voids” (Category IV). Category I was considered the optimum outcome among the four categories in view of the absence of voids. Categories II, III, and IV were considered less desirable because of the presence of voids. No differences in desirability among Categories II, III, and IV were considered.

Intra-rater reliability and inter-rater reliability: four categories

The three raters completed a calibration training session to identify coronal sealer/gutta-percha image patterns for each of the four categories. Each image was categorized independently by each rater.

Intra-rater reliability is defined as the consistency of the same rater in categorizing the same image on two different occasions. To assess the intra-rater reliability, three raters (IS, JD, and KV) examined all images twice with an interval of one week between examinations; the raters then

Table 2 Total counts and percentages of sealer images among four categories

Category	Swirled	Voids	Intermingled GP and sealer pattern	Total count		Percentage (%)	
				AH Plus	EndoSequence BC	AH Plus	EndoSequence BC
I	yes	no	swirled, no voids	27	11	16.4*	6.7
II	no	yes	uniform voids	7	7	4.2	4.2
III	no	yes	non-uniform voids	50	45	30.3	27.3
IV	yes	yes	swirled, with voids	81	102	49.1	61.8
				165	165	100.0	100.0

GP, gutta-percha. Five samples per sealer by three examiners; 11 images per sample. (11 images per sample)*15 = 165 per sealer; 2 sealers, therefore 330 images total.

*Statistical significance between sealers ($P < 0.01$)

compared the first image from the first week with the second one to determine whether the two matched.

Inter-rater reliability is defined as the agreement among different raters in categorizing the same image. To assess the inter-rater reliability, all images were examined and compared by the three raters (IS, JD, and KV) to confirm consistent categorization.

Statistical analysis

To establish intra-rater reliability for the same rater examining the same image on two different occasions, the intra-class correlation coefficient (ICC) was calculated together with the 95% confidence interval. Cohen's kappa is a measure of the agreement between two raters, where agreement due to chance is factored out. Fleiss' kappa was calculated to establish the inter-rater reliability for the three raters on the same image. Descriptive statistics of the number of images in each category were computed for the AH Plus and EndoSequence BC sealer groups. Chi-squared tests were conducted to determine whether significant differences existed between AH Plus and EndoSequence BC groups in each category. The data were analyzed using SPSS (version 27.0, IBM SPSS Inc., Chicago, IL, USA). Differences at $P < 0.05$ were considered statistically significant.

Results

Table 2 shows the total counts and percentages of sealer images placed in each category. In the AH Plus group, 16.4%, 4.2%, 30.3%, and 49.1% of the images were placed in Categories I, II, III, and IV, respectively, whereas the corresponding figures for the EndoSequence BC group were 6.7%, 4.2%, 27.3%, and 61.8%, respectively. In both the AH Plus and EndoSequence BC groups, the highest number of images were in Category IV and the lowest in Category II. Significant differences between the AH Plus and EndoSequence BC groups were evident only in Category I ($P < 0.01$), AH Plus having more areas without voids. The intra-rater reliability (intra-class correlation coefficient) was 0.55, and the 95% confidence interval was 0.411-0.668. The inter-rater reliability (Fleiss' kappa) was 0.34.

Discussion

In the present study using micro-CT, gutta-percha and sealer intermingled during obturation, creating four categories, including voids at the microscopic level. Figure 1 presents images of each category with the most clearly established patterns. Koo and Li [28] have interpreted an intra-rater reliability (intra-class correlation coefficient) of 0.55 as moderate agreement, and Landis and Koch [29] have interpreted an inter-rater reliability (Fleiss' kappa) of 0.34 as fair agreement. Despite training, the perception of image contours and definition of "uniform" varied among the three raters and for the same rater at different time points. As a result, the intra-rater reliability (intra-class correlation coefficient) and the inter-rater reliability (Fleiss' kappa) were lower than expected. Raters found it challenging to make a clear distinction among categories even with high image quality.

The number of Category IV images (swirled gutta-percha and sealer with voids) was highest in both the AH Plus and EndoSequence BC groups. These results in the coronal area concur with the report of Zare et al. [13], which assessed apical micro-voids in obturation using micro-CT. Among the four categories defined here, three (II, III, and IV) included voids. More than 80% of the images for both sealers included voids. Voids indicate imperfect sealing and a pathway for microleakage.

The number of Category II images (uniform voids) was lowest in both the AH Plus and EndoSequence BC groups. The difference between Categories II and III is whether voids are uniform or non-uniform. When the

3-D images were segmented to construct a high-resolution sagittal image, the shape of the voids may have been skewed depending on the angle of the tooth's central axis, which may explain why Category III (non-uniform voids) was more frequent than Category II (uniform voids).

The present study revealed significant differences in the void-free Category I between the AH Plus and EndoSequence BC groups ($P < 0.01$), being fewer for the tricalcium silicate sealer. Most heat devices offer a thermal working range of 150-250°C, with preferential use at 200°C [30]. Clinically, the sealer can be heated using heat devices, but the sealer temperature never exceeds 100°C when the heat devices are set at 200-250°C [14,31,32]. Evaporation of the organic liquid in the paste of the tricalcium silicate-based root canal sealer may have created bubbles or voids, leading to fewer void-free Category I images. Tricalcium silicate-based sealers set through a reaction with water and a formation of hydroxyapatite within the canals [4,33], the process requiring hours of setting after placement. In contrast, AH Plus sets as a result of a chemical reaction between the two pastes [4,34], which is accelerated by heat but does not create voids.

Using SEM, Chavarria-Bolanos et al. [19] found no apparent heat-induced compositional alterations or ultrastructural changes for AH Plus, indicating that it can be heated even to 230°C. On the contrary, Viapiana et al. [31] have reported that AH Plus sustained changes to its chemical structure after exposure to heat. Heran et al. [32] recommended that AH Plus should not be subjected to as high a temperature as 100°C due to deterioration of its properties and increased formation of voids. Among the physical properties of sealers, Yamauchi et al. examined the setting time, flow, and film thickness of AH Plus and EndoSequence BC sealers [20] and found a significant reduction of setting time and flow for both sealers at 100°C, which was expected in view of the chemical constituents.

The combined percentages of the three categories with voids (II, III, and IV) were 83.6% (AH Plus) and 93.3% (EndoSequence BC). This result contrasts with Celikten et al. [35], who found that EndoSequence BC sealer had the lowest percentage of voids in terms of volume in the apical third of root canals among AH Plus, EndoSequence BC, and ActivGP sealers; however, heat is not used in the apical area. Using single-cone obturation and non-destructive micro-CT 3-D imaging to analyze voids, Celikten et al. [35] noted that apical voids were not the same as coronal voids.

The present results are of clinical significance for completion of single-cone obturation. Prevention of coronal leakage is critical because canals may be contaminated by penetration of microorganisms after loss of coronal sealing or fracture of the remaining tooth [1,5,6]. In addition, the presence of micro-voids may create an infection focal point or pathway from the coronal to the apical portion of a tooth [4,36]. Excellent sealer adaptation at the interface is needed to prevent microleakage, inhibit infection, and contribute to the long-term clinical success of NSRCT. Therefore, to prevent coronal leakage and subsequent failure of NSRCT, intraorifice barriers are often placed in a coronal position relative to the root canal filling material. Glass ionomer and flowable composite resin are intraorifice barriers widely used in clinical practice [37]. As obturation is completed, the gutta-percha is removed to a level 1 to 2 mm apical to the cemento-enamel junction or the floor of the chamber in a molar. The intraorifice barrier material is then applied in the coronal 1 to 2 mm of the canal using the recommended instructions for the chosen material [Torabinejad M et al., Endodontic Principles and Practice: 345-6, 2022]. Understanding the interaction of materials can facilitate successful clinical obturation techniques.

The present study using micro-CT images demonstrated how gutta-percha and sealer intermingle within 0.5 mm of the coronal cut-off of gutta-percha. No intermingling was observed below the 0.5 mm level. Cold lateral condensation, single-cone, warm vertical, and carrier-based

[7,8] techniques use heat to cut the gutta-percha point; therefore, regardless of the obturation technique used, a clinician has the responsibility to mechanically remove 0.5 mm of the mingled coronal area, using, for instance, slow-speed round burs.

This is the first study to have used the single-cone technique to categorize patterns of gutta-percha and sealer intermingling upon heat application. Improving the coronal seal by eliminating the coronal 0.5 mm could enhance the adaptation at the interface between the gutta-percha point and the intraorifice barrier material, potentially leading to higher clinical success. Future studies comparing endodontic sealers with other obturation techniques are needed to address this knowledge gap about how heat application affects sealers both *in vitro* and clinically.

In conclusion, within the limitations of this study, Category IV (swirled gutta-percha and sealer with voids) accounted for the highest proportion of images, and Category II (uniform voids) accounted for the lowest proportion in both the AH Plus and EndoSequence BC groups. Significant differences between the AH Plus and EndoSequence BC groups were revealed in Category I (no voids) ($P < 0.01$). To establish a good seal to prevent coronal leakage, mechanical removal of 0.5 mm of the coronal seal should be performed before applying intraorifice barrier materials. If the clinician cannot remove this material mechanically, AH Plus would be better than EndoSequence BC because this sealer had fewer voids.

Acknowledgments

The authors thank Ms. Elizabeth J. Dyer and Ms. Cindy Stewart for reference support, Ms. Lori Rand for writing consultation and editing, and Mr. Oran Suta for medical/dental illustration. The authors gratefully acknowledge Dentsply Sirona and Brasseler for supplying the materials.

Conflict of interest

None.

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