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Evaluation of Gaps or Voids Occurring in Roots Filled with Three Different Sealers

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ABSTRACT

Objectives: The purpose of this in vitro study was to evaluate gaps or voids occurring in roots filled with three different sealers.

Methods: Thirty extracted human single-rooted teeth were decoronated, instrumented using NiTi rotary instruments, divided into three groups (n=10 per group) and obturated with one of the following: Epiphany with Resilon, MetaSEAL with gutta-percha or AH Plus with gutta-percha using the match-taper single-cone technique. After storage for one week in 100% humidity at 37°C, the teeth were horizontally sectioned (n=10). Photographs were taken from the coronal, median and apical parts of the roots using a stereomicroscope at 10X magnification, and the images were then transferred to a computer. The mathematical method known as the 'Affine Transformation' was used for the transformation of pixel coordinates to ground coordinates in the Netcad Software program. The mean areas (μm^2) of the gaps between the sealer and root dentin or gutta percha/resilon and the gaps between the sealer and/or voids inside the sealer mass were measured, scored on a 0-3 scale and statistically analyzed with the Kruskal-Wallis test.

Results: The mean total area of gaps or voids for each sealer was 4631.80 μm^2 for the Epiphany-Resilon, 3826.80 μm^2 for the MetaSEAL-gutta-percha and 31334 μm^2 for the AH Plus-gutta-percha. The MetaSEAL-gutta-percha group showed more gap or void-free interfaces. No significant differences were found among the sealers in the scores for the gap areas ($P<.05$), and the MetaSEAL showed similar interfaces with Epiphany.

Conclusions: No significant differences in the mean areas of gaps or voids were found among the tested resin-based sealers. (Eur J Dent 2010;4:101-109)

Key words: Gap; Void; Sealer; Affine transformation; Endodontic treatment.

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INTRODUCTION

The goal of an endodontic treatment is to eliminate microbial challenges from the root canal system and to develop a complete seal using a stable and biocompatible material.[1] Improvements in adhesive technology have focused research efforts on bonding to root canal walls, and resin-bonded root-canal sealers were then suggested for use.[2-5] The Resilon/Epiphany system (Pentron Clinical Technologies, LLC, Wallingford, CT, US)[3] is one of these sealers and was introduced as a promising root canal obturation material. Resilon (Resilon Research, LLC, Madison, CT, US) is a synthetic polymer-based material and contains bioactive glass and radiopaque fillers.[6] The Resilon/Epiphany (Pentron Clinical Technologies, Wallingford, CT, US) combination forms a monoblock within the root canal.[7] Furthermore, the dual-cure characteristic gives the system an advantage.[8]

Dentine-bonding agents may have the potential to enhance the root canal seal. Conventional or multi-step bonding systems could have an incomplete infiltration of the demineralized dentine, resulting in unprotected collagen and hydroxyapatite crystals that are vulnerable to degradation. Self-etch adhesive systems were developed as an alternative. In self-etch systems, the acidic part of the primer dissolves the smear layer, incorporating it into the mixture as it demineralizes the dentine and encapsulates the collagen fibers and hydroxyapatite crystals.[9,10]

Recently, a 4-methacryloyloxyethyl trimellitate anhydride (4-META) containing polymethyl mathacrylate based (PMMA) dual-curable and self-etching resin cement has been introduced for endodontic use (MetaSEAL; Parkell Inc., Farmington, NY, USA). Methacrylates with hydrophobic and hydrophilic groups such as 4-META promote monomer diffusion into the acid-conditioned and underlying intact dentine, and their polymerization produces functional hybridized dentin.[11,12] The formation of hybridized dentin is the major mechanism of bonding and a high quality hybridized dentine[13] resists acid challenge.[12] A minimal hybrid layer was seen in radicular dentin with MetaSEAL, and the lower dislocation resistance in MetaSEAL filled canals challenges the use of a self-adhesive bonding mechanism to create continuous bonds inside the root canals.[14]

Several studies were done to evaluate sealers in terms of their susceptibility to degradation,[15] cytotoxicity,[16] bondability,[17,18] sealing ability[19,20] and biocompatibility.[21] Mutal and Gani reported that there were few reports available on the presence of voids within the sealer mass.[22] Studies were later done to evaluate the gaps or voids within the sealer either using stereomicroscopes, digital images and computer program[23-26] or using micro-CT.[27]

For evaluating the gaps or voids on digital images, calculations are necessary. The most common method of transformation from the machine coordinate system into the true image coordinate system is the 'Affine Transformation' method. The Affine Transformation is generally used in engineering and photogrammetric fields. The method basically depends on the transformation of pixel coordinates to ground coordinates, which is expressed by the following equation:[28]

$$\begin{pmatrix} \xi \\ \eta \end{pmatrix} = \begin{pmatrix} a_{01} \\ a_{02} \end{pmatrix} + \begin{pmatrix} a_{11} & a_{21} \\ a_{12} & a_{22} \end{pmatrix} \begin{pmatrix} \xi' \\ \eta' \end{pmatrix}$$

a_{01}, a_{02}, a_{11}, a_{21} a_{12}, a_{22}: affine transformation parameters; ξ', η': pixel coordinates; ξ, η: ground control point coordinates.

The aim of this study was to quantitatively evaluate the gaps (between the sealer and root dentin or gutta percha/resilon and sealer) or voids (within the sealer mass) in roots filled with three different sealers, using a computer program that makes affine transformation calculations (NetCad, Ak Mühendislik Ltd. Sti. Ankara, Turkey) and to evaluate whether the distribution of the gaps or voids inside the root canal system differ according to the sealer or region.

MATERIALS AND METHODS

Extracted human teeth with straight roots and fully formed apices were selected for this study. The teeth were scaled with a periodontal scaler to remove soft tissue and calculus; radiographs were taken to confirm the presence of a single canal and then decoronated at the cemento-enamel junction to leave a root length of 11 mm using a diamond bur (Dia Burs, Mani Inc., Utsunomiya, Tochigi, Japan) under cooling. Thirty-three teeth with round canals were selected, and the patency of the root canals was verified with a #15 K-file (Dentsply Maillefer, Tulsa, OK). The working length was determined by inserting the file into the canal until it was just visible at the apical foramen, then subtracting 1 mm from the measured length. The canals were then instrumented using the crown-down technique with ProFile 0.04 tapered NiTi rotary instruments (Dentsply, Tulsa Dental, Tulsa, OK) until a #45 file fit at working length. For irrigation solution, 2.5 ml of 5% NaOCl, was used, and the final rinse was done with 3 ml of 17% EDTA followed by 3 ml of distilled water. The canals were dried with paper points (Gapadent Co. Ltd. Xinkou Town, Tianjin, China), randomly divided into 3 groups (n=11) and obturated using a single-cone technique with one of the sealers given in Table 1. Details are as follows:

Group 1: The Epiphany primer was introduced into the canal with a paper point, and the Epiphany sealer was applied to the canal with a lentulo spiral filler (Dentsply, Maillefer, Switzerland). A size 45, .04 tapered Resilon point was coated with Epiphany sealer and fitted to working length with tug-back. The excess material was cleaned, and the roots were light-cured from the coronal side for 40 s using a halogen light-curing unit (Lunar, Benlioglu Dental, İstanbul, Turkey) at an intensity of 620 mW/cm^2. The excess Resilon was removed from the coronal cavity up to the level of the cemento-enamel junction with a hot instrument.

Group 2: The MetaSEAL was hand-mixed on a mixing pad using one scoop of powder and three drops of liquid for 30 seconds and applied to the canal with a lentulo spiral filler. A size 45, .04 tapered gutta-percha point (DiaDent Group Int., Canada) was coated with the sealer and introduced into the root canal. The excess material was removed from the coronal surface and light-cured for 40 s. Excess gutta-percha was removed from the coronal cavity up to the level of the cemento-enamel junction with a hot instrument.

Group 3: The AH Plus (De Trey, Dentsply, Konstanz, DE) was applied to the root canal with a lentulo spiral filler. A size 45, .04 tapered gutta-percha point was coated with AH Plus and introduced into the canals with tug-back. Excess material was removed, and the excess gutta-percha was removed with a hot instrument.

Obturated roots were kept in 100% humidity conditions (37°C) for one week. To examine the resin sealer-dentin interfaces, one root from each group was randomly selected for Scanning Electron Microscopy (SEM) analysis.

The apical 2 mm of the remaining roots (n=10) were removed using a slow-speed, water-cooled diamond saw (Isomet, Buehler, Lake Bluff, IL). Each root was then sectioned at three levels (coronal, median and apical). The thickness of the sections was approximately 3±0.5 mm. A total of 90 section surfaces were obtained. Digital images were taken from the apical side of each section in combination with a micrometer (Clemex, CL-04-114-0607, Longueuil Canada), using a stereomicroscope (Olympus SZ40) at 10X magnification (Figure 1a, b and c). The images were then transferred to a computer at the Photogrammetric Laboratory of the Faculty of Engineering (University of Selcuk, Konya, Turkey) and evaluated for the surface area of all the gaps or voids. A total of three measurements were done for each root (coronal apical and median). For this purpose, an affine transformation was done in the Netcad Software (Ak Mühendislik Ltd. Şti. Ankara, Turkey), and the surface area of the gaps or voids were calculated as µm^2 (Figure 2). Scoring was done on a 0-3 scale according to accumulation of the gaps or voids. '0'

Table 1. Ingredients, manufacturers and batch number of the sealers.

Sealer	Ingredients	Manufacturer	Batch
AH Plus	Paste A: Bisphenol-A epoxy resin, Bisphenol-F, epoxy resin, Calcium tungstate, Zirconium oxide, Silica, Iron oxide pigments. Paste B: Dibenziyldiamine,Aminoadamantane, Tricylodecane-diamine, Calcium tungstate, Zirconium oxide, Silica, Silicone oil.	De Trey / Dentsply, Konstanz, Germany	0602002055
MetaSEAL	Liquid: 4-META,monofunctionalmethacrylate monomer, multifunctional Macrylate monomers and photo-initiators; Powder: Mixture of Zirconium oxide filler, SiO2 filler and polymerization initiators.	Parkell Inc., NY	Powder: 060309 Liquid: 051004
Epiphany	BisGMA, UDMA, hydrophilic methacrylates	Pentron, Wallingford, CT, USA	103856

represents no gaps or voids, '1' represents gaps or voids observed at one section and '3' represents gaps or voids observed at 3 sections (apical, median and coronal). The data was then statistically analyzed with a Kruskal-Wallis test.

The roots selected for SEM analysis were sectioned vertically into two pieces through the sealer, and each surface was then polished with 400 to 1200 grit silicon carbide abrasive papers. The interfaces were subjected to 10% phosphoric acid treatment for 3-5 s, followed by 5% sodium hypochlorite immersion for 5 min.[8] After being rinsed with distilled water, the samples were kept at room temperature for desiccation (24 h). Gold sputter coated interfaces were evaluated under SEM (JSM 5600, JEOL Ltd., Tokyo, Japan) operated at 20 kV.

RESULTS

The measured surface areas of gaps or voids according to the materials and regions are shown in Table 2 (μm^2). When the scored data were analyzed, no significant differences were found among the sealers (P=0.60). Table 2 shows the distribution of the percentage of the gap or void-free sections by region and material. The AH Plus showed 100% gap or void-free interfaces at the apical region and the Epiphany showed 100% gap or void-free interfaces at the median. No significant differences were found among the sealers for the distribution of the gaps or voids by region (coronal, median or apical; P>.05).

When the interfaces of one sample from each group was observed under SEM, both the AH Plus and MetaSEAL samples showed an excellent adaptation to root dentin at the apical region (Fig-

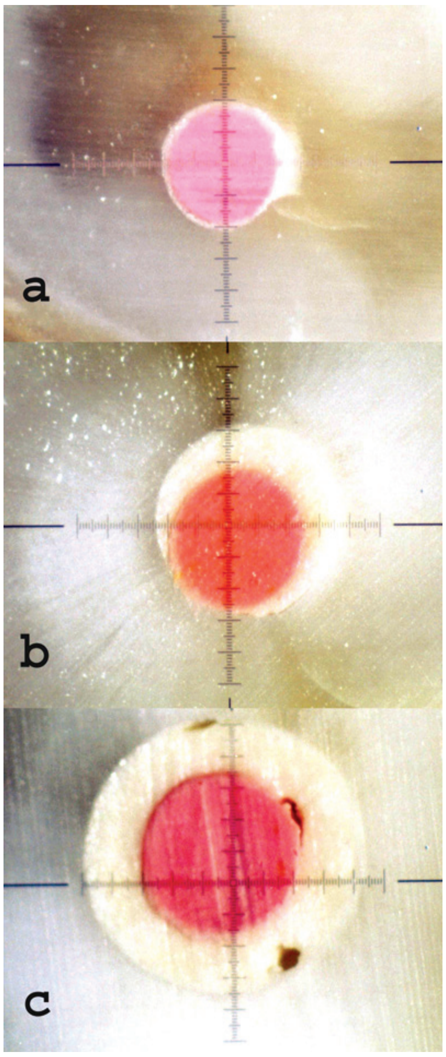

Figure 1. a. Microscopic image of the apical part of a sample. Digital images were taken in combination with a micrometer. **b.** Microscopic image of the median part of the same sample. **c.** Microscopic image of the median part of the same sample.

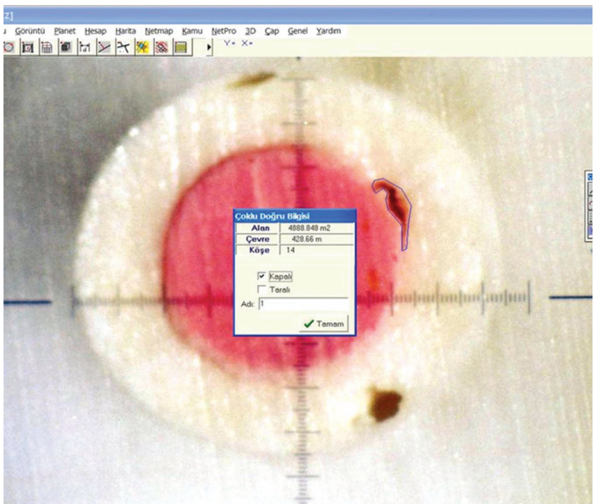

Figure 2. Affine transformation of the coronal part of a sample in the Netcad Software.

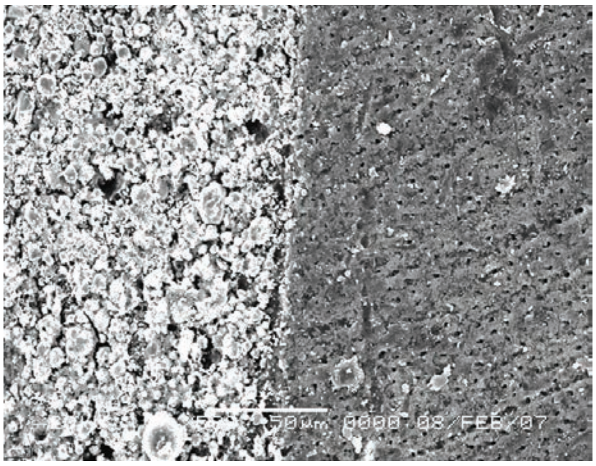

Figure 3. iSEM micrograph (500X) of a specimen that was filled with AH Plus and gutta-percha taken at a level of 2 mm from the apex. No void could be seen between the filled resin sealer and dentin. The sealer is closely adapted to the root dentine and gutta-percha.

ures 3 and 4) and showed small voids within the sealer mass at the coronal region (Figures 5 and 6). The Epiphany sample showed gap formation at the apical region (Figure 7), and the sealer was closely adapted to the root dentin surfaces at the coronal region (Figure 8).

DISCUSSION

An aim of obturation is to have the maximum amount of gutta-percha filling. Wesselink reported that the amount of sealer should be minimized, and the solid nucleus of gutta-percha should be maximized for better sealing.[29] The lateral condensation technique, as classically described, involves the use of an ISO-standardized 0.2 mm/mm tapered master gutta-percha cone. However, lateral condensation, unlike vertical condensation, does not create a homogenous mass of gutta-percha. Therefore, filling with a master cone with a larger taper may be advantageous because a larger and more uniform mass of gutta-percha is introduced into the root canal.[30] Gordon et al indicated that the single cone results were not significantly different from the lateral condensation results, indicating that the method was comparable with lateral condensation.[25] Obturating straight root canals in vitro with laterally condensed .06 tapered gutta-percha master cones that match the shape of .06 tapered nickel-titanium rotary instruments prevent complete bacterial penetration as effectively as laterally condensed .02 tapered master cones.[30] If a round shape is made in the canal preparation, a well-fit single cone with sealer can be used for adequate obturation, and there have been multiple studies in which a single cone method of obturation was successfully used.[25,31-33] In the present study, root canals were instrumented with ProFile .04 tapered NiTi rotary instruments to improve preparation of a uniformly round space. MetaSEAL is recommended for use exclusively with cold compaction or single-cone techniques;[14] therefore, the single cone technique was used during the obturation of the canals using a .04 tapered gutta-percha or Resilon. Although the match-taper single-cone technique was used, the sealer thickness was increased from the apical to coronal regions in all samples. The thinnest sealer was observed at the apical region and the thickest sealer was observed at coronal region (Figure 1a, b and c). When the distribution of the gaps or voids was evaluated, only the AH Plus group showed 100% gap or void-free interfaces at

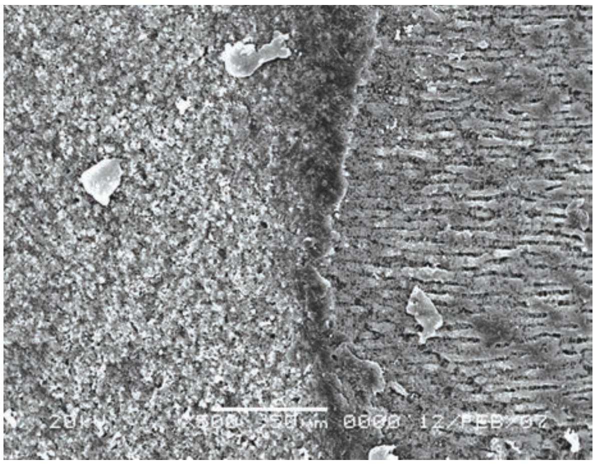

Figure 4. SEM micrograph (500X) of longitudinal section of a root filled with MetaSEAL and gutta-percha taken at a level of 2 mm from the apex. No void could be discerned between the sealer and the root dentin, and no resin tags could be identified

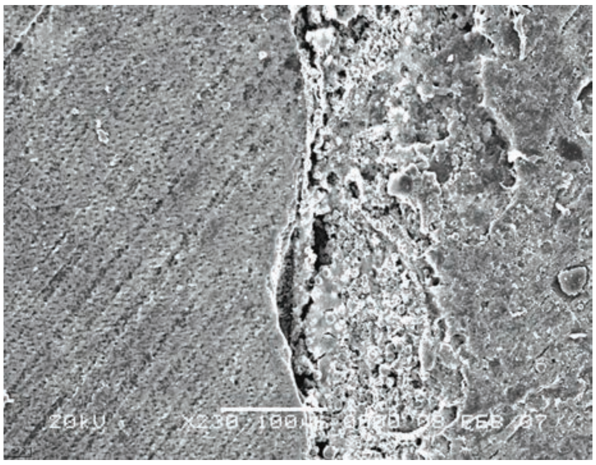

Figure 5. SEM micrograph (230X) of longitudinal section of the same specimen filled with AH Plus and gutta-percha at a level of 3 mm from the coronal. A void is evident between the sealer and root dentin. No resin tags could be identified in dentinal tubules.

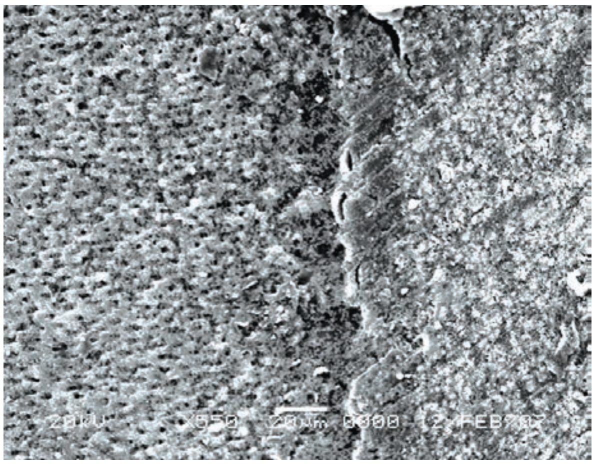

Figure 6. SEM micrograph (550X) of coronal region of the same specimen taken at a level of 3 mm from the coronal side. The root was filled with MetaSEAL and gutta-percha. Small voids were identified between the sealer and root dentin. No resin tags could be identified.

the apical region. This result shows that maximizing the solid nucleus of gutta-percha and minimizing the amount of sealer is an effective method to prevent gap or void formation, at least for AH Plus. On the other hand, decreasing the sealer thickness with Resilon or gutta-percha could not prevent gap or void formation in the MetaSEAL (10%) and Epiphany groups (20%) (Table 2, Figure 7).

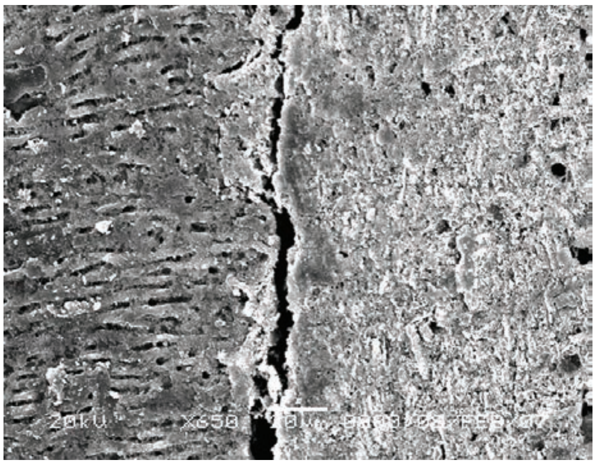

Figure 7. SEM micrograph (650X) of apical region of a root filled with Epiphany and Resilon taken at a level of 2 mm from the apex. A void could be seen between the sealer and Resilon. The sealer is very thin, and the resin penetration into the dentinal tubules cannot be identified.

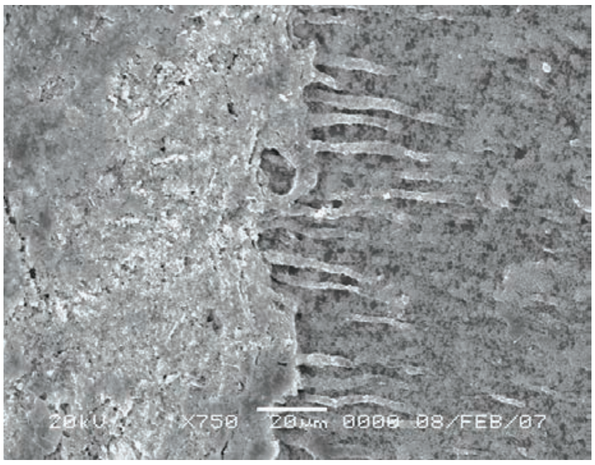

Figure 8. SEM micrograph (750X) of coronal region of the same specimen root filled with Epiphany and Resilon. The sealer is closely adapted to the root dentine, and numerous resin tags extended into the dentin tubules.

Table 2. Total area of the gaps or voids (μm^2) and percentage of gap- or void-free interfaces according to the regions.

	AH Plus / Gutta-percha			MetaSEAL / Gutta-percha			Epiphany / Resilon		
	Apical	Median	Coronal	Apical	Median	Coronal	Apical	Median	Coronal
%	100	80	50	80	80	90	80	100	70
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	580^{s} 432^{g}	2174^{s}	0	1183^{g}	0	0
5	0	10844^{g} 5515^{s}	349632^{s} 313870^{d}	0	0	16209^{d} 553^{s}	0	0	6061^{d}
6	0	0	118226^{s} 25603^{g}	0	0	0	0	0	14685^{r}
7	0	0	0	0	0	0	12008^{d}	0	0
8	0	0	6302^{s}	0	18320^{s}	0	0	0	0
9	0	0	7241^{s}	0	0	0	0	0	12381^{r}
10	0	338450^{s}	461112^{s}	0	0	0	0	0	0

g: Gaps between gutta-percha or Resilon and sealant; s: Voids inside the sealant; d: Gaps between the sealant and root dentin; r: Gaps between Resilon and sealant.

Structural deficiencies are generally originated from the air trapped in the sealer mass during mixing or transferring of the sealer.[22] Mutal et al indicated that the presence of structural deficiencies also depend on the physical properties of the sealer, such as density or flow.[22] Unlike Epiphany and AH Plus, the MetaSEAL consists of powder and liquid. The material has a long working time (30 min) and an 8 min curing time (unpublished data by Parkell). All the samples were light-cured from the coronal region for 40 s as in Epiphany Group. The results indicated that 20% of samples showed void formation at the median, and 90% of the samples were gap or void-free at both the apical and coronal regions. The Epiphany group showed 100% gap or void-free interfaces at the median (Table 4). No significant differences were found between the Epiphany and MetaSEAL groups (P=0.60).

The amount of resin flow that occurs during polymerization is determined by the configuration of the cavity, and the cavity configuration factor (C-factor) is defined as the ratio of the bonded to the unbonded surface area.[34] Resin-based sealers are bonded 360 degrees around the periphery of the canal, and only the surface area at the top of the canal orifice allows flow of the sealer during shrinkage. A root canal could create C-factors of 20 to 100 depending on the diameter and length of the canal.[35] Tay et al indicated that in root canals, C-factors can be over 1000. Large polymerization stresses during setting may lead to debonding of the resin from the canal wall or may cause void formation along the periphery of the root filling.[36] Stress relief by resin flow partially depends upon resin film thickness.[37,38] However, in a root canal, stress relief by flow is not sufficient because the unbonded surface area becomes smaller, and the forces of polymerization shrinkage can exceed the resin bond strength to root dentine, permitting debonding on one side of the filling to relieve stress.[36] In this study, AH Plus showed 50%, Epiphany 50% and MetaSEAL showed 70% gap-free interfaces from the apical to coronal regions (Table 2). On the other hand, when the samples with gaps were evaluated, it was observed that when the apical region was 100% gap-free, there was a gap at the coronal (AH Plus) or median regions, and when the median was 100% gap-free, then there were gaps or voids at both the apical and coronal regions (Epiphany). These results confirm the idea that the C-factor affects the performance of the resin-based sealers, and as a result of the shrinkage stresses, debonded areas can occur.

To overcome shrinkage stresses, the materials should have a strong adhesion. In the present study, MetaSEAL and Epiphany showed more 100% gap-free interfaces than AH Plus (not sig.). Their adhesion ability seemed to be high enough to overcome shrinkage stresses. A slow polymerizing sealer can help relieve the shrinkage stress via resin flow. MetaSEAL polymerizes in room temperature in 30 minutes. Light-curing to create an immediate coronal seal may prevent flow of resin sealer.[39] In the present study, both Epiphany and MetaSEAL groups were light cured from the coronal region according to the manufacturers' instructions. The results might be different if these sealers were set without additional light curing.

Obturation quality is generally determined by evaluating the amount of apical or coronal leakage in root-filled teeth. Wu et al reported that the thickness of the sealer layer is a factor that can affect the sealing ability.[40] In a microbial leakage study, Shipper et al found Resilon groups superior to gutta-percha groups.[5]

Examination of fully hydrated specimens by environmental scanning electron microscope (ESEM) is essential for differentiating genuine voids between root filling and dentin that are susceptible to leakage of microorganisms and antigens, from potential artifactual voids created after vacuum desiccation in conventional SEM's.[6,41] In the present study, the evaluation of the voids was done on digital images taken from hydrated samples under stereomicroscope. A sample from each group was evaluated using conventional SEM. Kataoka et al evaluated the sealing ability of a resin-based root canal sealer and conducted tensile bond strength measurements, the dye penetration test and SEM observation.[42] The results indicated that the dye penetration test results were supported by the conventional SEM observations. In the present study, when the SEM images were evaluated, the results were similar to the digital image evaluation results, although ESEM was not used.

In this study, the 'Affine Transformation Method' was used to calculate the area of the gaps or voids. Although the Affine Transformation Method is generally used in engineering and photogrammetric fields, in this paper, we introduced this technique for the quantitative analyses of microscopic images of sectioned roots. Three sections were obtained from each root. A micrometer and a stereomicroscope were used to obtain images, and the Netcad Software was used for the Affine Transformation. The operator who defined the voids for analysis using the Netcad Software was blinded the assigned sealer of each sample. The same parameters were used for all samples. This method appears to be a practical method for calculating surface areas from digital photographs. Other methods for the evaluation of root fillings include histological sectioning and subsequent evaluation of voids by image analysis,[32,43] radiographic techniques,[44] the density evaluation using weighing[45] or measuring the amount of spreader penetration[30] or the micro-CT technique.[27] The technique used in this study was easy to use and allowed detailed evaluation of the voids verified with the microscope or with digital images of high resolution. One of the limitations of this study was the destruction of the samples and structural loss during cutting with the diamond saws given the thickness of the saw. Three sections from one root representing three different regions (apical, median and coronal) were evaluated in this study. This technique did not allow for three dimensional evaluation of the gaps or voids, but it can be improved by increasing the number of the sections. Future studies are needed to improve the use of this technique in the dental field.

CONCLUSIONS

Within the limitations of this study, the following results can be drawn:

• The recently developed 4-META containing sealer, MetaSEAL, showed similar interfaces with the sealer Epiphany.

• When the mean surface area of the voids was scored on a 0-3 scale, no significant differences were found among the groups.

• The 'Affine Transformation Method' allowed evaluation of the gaps or voids on the digital images of root filled teeth.

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