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Retreatment efficacy of the Epiphany soft resin obturation system

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Abstract

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Aim To assess the efficacy of retreatment of canals filled with the Epiphany System with and without solvent, with particular reference to the extent of canal enlargement during retreatment.

Methodology Sixty roots with canals prepared to apical size 45 were embedded in resin blocks and sectioned vertically. Digital micrographs of canal walls were captured. Roots were re-assembled and filled with Epiphany/Resilon (experimental) or gutta-percha/AH Plus (control). After 8 weeks, canals were retreated to size 45 with or without chloroform, and the time recorded. Roots were split, imaged, re-assembled, retreated to size 55, split and imaged. Root-filling residue, traced at three canal levels, was expressed as percentage of canal surface.

Results Residue percentage was greater (*t*-test, $P < 0.01$) in the experimental group than in the control. Most residue in all specimens was in the apical third (ANOVA, $P < 0.01$). Chloroform and enlargement to size 55 decreased residue in both groups (*t*-test, $P < 0.01$). Retreatment time was longer in the experimental group ($P < 0.05$), and reduced by chloroform in both groups ($P < 0.05$).

Conclusions The Epiphany System was retreatable with and without chloroform, with lesser efficacy than gutta-percha and AH Plus sealer.

Keywords: gutta-percha, Resilon, retreatment.

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Introduction

Cross-sectional studies (Kirkevang *et al.* 2001, Dugas *et al.* 2003) have demonstrated persistent apical periodontitis associated with over 45% of root-filled teeth in the population. Persistent apical periodontitis is caused mainly by root canal bacteria that survive treatment; therefore, it is frequently treated by means of orthograde retreatment (Friedman 2002). The retreatment procedure comprises re-entry into the root canal system and removal of the existing root filling throughout the canal length, to allow disinfection of the root canal space and creation of favourable conditions for periradicular healing (Stabholz & Friedman 1988). In order to allow retreatment when indicated, the materials used for root filling should be retreatable (Grossman 1970).

The most widely accepted root-filling material is gutta-percha in conjunction with a variety of sealers (Grossman 1970). Gutta-percha can be removed from the root canal with hand, rotary, and ultrasonic files (Wilcox *et al.* 1987, Wilcox 1989, Friedman *et al.* 1992, 1993, Moshonov *et al.* 1994, Bramante & Betti 2000, Sae-Lim *et al.* 2000, Ferreira *et al.* 2001, Masiero & Barletta 2005, Ezzie *et al.* 2006, de Oliveira *et al.* 2006, Schirrmeister *et al.* 2006a,b), as well as by laser irradiation (Viducic *et al.* 2003). Furthermore, removal of gutta-percha is facilitated by the use of heat (Wilcox *et al.* 1987, Wilcox 1989) and solvents such as chloroform, xylol, eucalyptol, halothane or turpentine (Tamse *et al.* 1986, Friedman *et al.* 1990). Despite its relatively easy removal during retreatment, *in vitro* studies (Wilcox *et al.* 1987, Wilcox 1989, Friedman

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et al. 1992, 1993, Moshonov *et al.* 1994, Bramante & Betti 2000, Sae-Lim *et al.* 2000, Ferreira *et al.* 2001, Viducic *et al.* 2003, Masiero & Barletta 2005, Ezzie *et al.* 2006, de Oliveira *et al.* 2006, Schirrmeister *et al.* 2006a,b) into the efficacy of retreatment procedures have invariably demonstrated residue of root-filling material on the canal walls, regardless of the sealer used and the method of retreatment. It has been suggested that such residue may be minimized if canal enlargement during retreatment exceeds that achieved prior to root filling (Friedman *et al.* 1992, 1993, Moshonov *et al.* 1994). To date this suggestion has not been supported by research data.

In recent years, there has been an increasing concern about the poor sealing properties of the conventional root-filling materials, gutta-percha and the different sealer cements. *In vitro* studies (Torabinejad *et al.* 1990, Khayat *et al.* 1993) have demonstrated microleakage in canals filled with these materials that may allow ingress and propagation of bacteria resulting in infection (Friedman *et al.* 1997, Shipper *et al.* 2005). In response to the shortcomings of gutta-percha and conventional sealers, the new Epiphany Soft Resin Endodontic Obturating System (Pentron Clinical Technologies, Willingford, CT, USA) has been introduced. This system consists of the core material Resilon, a thermoplastic, synthetic polymer resin engineered to have similar handling properties as gutta-percha, and the Epiphany sealer, a dual curable composite resin. The Epiphany sealer can be light-cured for an immediate coronal seal, whilst apically the sealer cures in approximately 25 min. The Epiphany System is compatible with all current root-filling techniques, facilitating its applicability with a minimal learning curve.

The Epiphany System is expected to form a 'monoblock' within the canal space, whereby the core (Resilon) is bonded to the sealer (Epiphany), and the resulting complex is bonded to the root dentine by the resin-based primer (Teixeira *et al.* 2004a). Such a monoblock has been suggested to reduce bacterial ingress pathways and to strengthen the root to some extent (Shipper & Trope 2004, Shipper *et al.* 2004, Teixeira *et al.* 2004b, Shipper *et al.* 2005). Other advantageous properties of the Epiphany System include high radiopacity, tissue compatibility, minimal shrinkage and resorbability of the sealer when expressed periapically (Teixeira *et al.* 2004a).

The manufacturer of the Epiphany System suggests that it is retreatable, by dissolving the core with conventional gutta-percha solvents and removing the sealer with files. Recent studies (Ezzie *et al.* 2006, de Oliveira *et al.* 2006, Schirrmeister *et al.* 2006b) have suggested that the Epiphany System is retreatable, with better efficacy than gutta-percha and an epoxy resin-based sealer. In two of these studies (Ezzie *et al.* 2006, de Oliveira *et al.* 2006), the root fillings were softened with heat or chloroform that facilitate the retreatment procedure (Tamse *et al.* 1986, Wilcox *et al.* 1987, Wilcox 1989, Friedman *et al.* 1990). No assessment was made of the influence of the softening on retreatment efficacy. Furthermore, in all these studies (Ezzie *et al.* 2006, de Oliveira *et al.* 2006, Schirrmeister *et al.* 2006b), retreated canals were enlarged beyond the size before root filling. It has been suggested that such enlargement may enhance the efficacy of retreatment (Friedman *et al.* 1992, 1993, Moshonov *et al.* 1994). Thus, the purpose of this study, was to assess the efficacy of retreatment of canals filled with the Epiphany System with and without solvent, with particular reference to the extent of canal enlargement during retreatment.

Materials and methods

Sample size calculation

Based on previous studies on retreatment efficacy (Friedman *et al.* 1992, 1993, Moshonov *et al.* 1994), a difference of 30% in the amount of root-filling residue was expected between the two root-filling materials. This difference suggested a sample size of 60 teeth for an analysis with 80% power and 5% significance level.

Root specimens

Sixty extracted human maxillary incisors with straight bulky roots were cleaned of attached soft tissue, and stored in 0.2% thymol (Sigma Chemical Co., St Louis, MO, USA) solution until used. Standard access cavities were prepared with high-speed diamond burs under water spray. The teeth were decoronated at 10 mm from root end to standardize their length. Apical patency was established by inserting an ISO size 15 K-type file (K-flex; Kerr Co., Romulus, MI, USA) through the canal to 1 mm beyond the apex. The working length was established at 1 mm short of the file's emergence at the apical foramen. The coronal portion of the canals was flared with Gates-Glidden drills sizes 3 and 2 (Maillefer Dentsply, Ballaigues, Switzerland). The remaining canal space was shaped in a crown-down manner with K3 instruments with 0.04 taper (Sybron Endo Inc., Newport Beach, CA, USA) to

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size 45 at the working length. Apical patency was maintained with size 15 K-type files. Canals were intermittently irrigated with 5 mL of 2.5% NaOCl and finally irrigated with 5 mL of 17% EDTA and sterile saline to wash out NaOCl. After drying with paper points the canals were sealed coronally with Cavit (Premier, Norristown, PA, USA). A small amount of wax was placed at the apex to prevent inflow of acrylic resin when embedding the roots, as described below.

Embedding blocks

Plastic containers were used to embed the roots in clear acrylic resin. Two 3 mm-wide metal rods, intended for fixation, were inserted horizontally through the plastic container walls parallel to each other and approximately 10 mm apart. Clear self-curing acrylic resin (ETI, Fields Landing, CA, USA) was poured into the container until full. The root was inserted vertically into the acrylic at the centre of the container between the two fixation rods (Fig. 1). After setting of the acrylic, the plastic casing was removed leaving the acrylic block with the embedded root and fixation rods.

To prepare each root for viewing of the canal wall surface, the fixation rods were withdrawn and the acrylic block containing the root was sectioned vertically in the buccal–lingual plane in a Buehler Isomet sectioning machine (Buehler Ltd., Evanston, IL, USA). A diamond disk of 150 μm thickness (Diamond Wafering Blade; Micro Metallurgical Ltd., Thornhill, ON, Canada) was used at 300 rpm. An effort was made to section the roots through the root canal into two equal halves. After sectioning, any resulting dust was removed by a short air blast. A sharp blade was then used to mark each split root half at 3 mm intervals to demarcate the apical, middle and coronal segments.

Both the split canal walls of each specimen were observed under a dissecting microscope (Wild Light; Tritech Research, Inc, Los Angeles, CA, USA) equipped with a Spat Insight video camera (Tritech Research) at 16× magnification. Digital micrographic images were captured of the canal coronal, middle and apical segments (Fig. 2). These images were stored in a computer, and used as a baseline for the future stages of the study. Next, the fixation rods were used to precisely re-assemble the two halves of the acrylic block.

Root filling

The specimens were randomly assigned to two equal groups ($n = 30$). The canals of specimens in the experimental group were filled with the Epiphany System (Pentron Clinical Technologies) and the canals in the control group were filled with gutta-percha and AH Plus sealer (De Trey, Zurich, Switzerland). A size 45 master cone was fitted in each canal with tug back at working length. Canals in the experimental group were conditioned with Epiphany self-etching primer, applied with soaked paper points. In both groups the sealer was placed into the canal by means of the master cone, and the root filling was laterally condensed with accessory cones using a size 25 finger spreader (Kerr Co.). The Touch 'n Heat device (Kerr Co.) was used to sear the filling material at the canal orifice. In the experimental group the coronal surface of the root filling was light-cured for 40 s. All canals were sealed with Cavit (Premier) and the specimens immediately placed in an anaerobic incubator at 37 °C for 8 weeks. To reduce inter-operator variables, each canal was prepared and filled by the same operator (A.H.).

For both groups the density of the root filling in each specimen was assessed by exposing two radiographs,

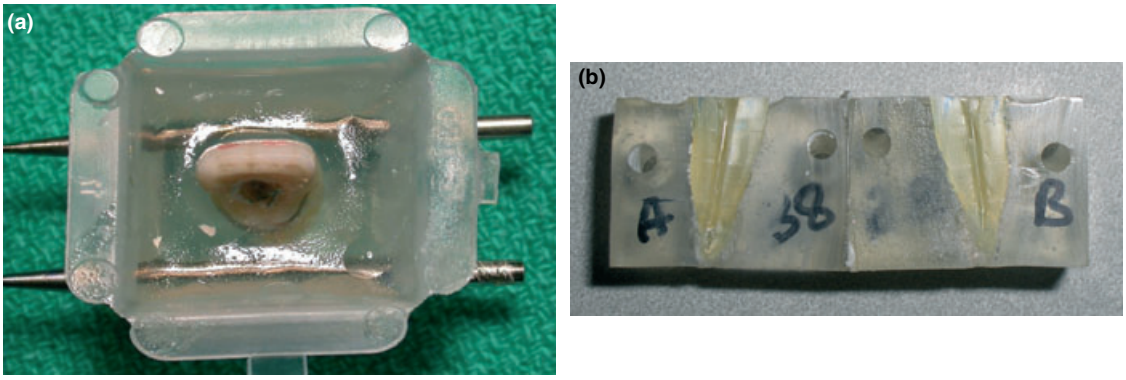

Figure 1 Photograph of tooth specimen embedded in an acrylic block, before (a) and after sectioning (b).

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Figure 2 Composite photomicrograph of the coronal, middle and apical segments of half a root specimen before root filling. Note debris remaining on canal walls.

one from the buccal aspect and one from the lingual aspect of the root. The fillings were considered adequate if they appeared to be dense without voids present and if they extended within 1 mm of the root end. Four inadequately filled specimens, two from each group, were discarded and replaced by new specimens.

Retreatment technique

Size 3 Gates-Glidden drills were used to remove the coronal 2 mm of the root filling. The filled specimens in each group were then randomly assigned to two retreatment method subgroups ($n = 15$). In the solvent subgroup, a 0.1 mL drop of chloroform was dispensed from an insulin syringe into the canal orifice. In the nosolvent subgroup, chloroform was not used. All canals were retreated with K3 rotary instruments with 0.04 taper operated in an electric motor handpiece (Dentsply Tulsa Dental Products, Tulsa, OK, USA) at 350 rpm, in a crown down sequence. The root-filling material was gradually removed using light apical pressure, until the working length was reached with a size 45, 0.04 taper instrument. During the retreatment procedure root canals were constantly irrigated with 2.5% NaOCl. The total time required in each specimen to attain the working length and complete retreatment with the size 45 instrument was measured with a stopwatch to the nearest second.

After reaching the working length with the size 45 instrument the canals were irrigated with 5 mL 2.5% NaOCl and 5 mL of sterile saline and dried with paper points. The fixation rods were withdrawn and the acrylic block split in half to assess canal cleanliness. Both canal walls were observed under the dissecting microscope for root-filling material residue at the coronal, middle, and apical level. Micrographs of each canal segment were captured digitally and stored in a computer (Fig. 3).

The blocks were then re-assembled and retreatment continued with 0.02 taper K-type hand files (Kerr Co.) to size 55 at working length. After reaching the working length with the size 55 instrument the canals were irrigated with 5 mL 2.5% NaOCl followed by 5 mL of sterile saline, and dried with paper points. The fixation rods were withdrawn and the block split again as before. The assessment procedure was repeated, and images captured of the canal walls at the coronal, middle and apical level.

During the retreatment procedure the K3 instruments and hand files were used in a maximum of three canals each. If unwinding occurred the instruments were replaced by new ones.

Outcome assessment

The amount of residue on canal walls was quantified with the software program Sigma Scan (Aspire Software International, Ashburn, VA, USA). Areas covered with root-filling residue were traced in each canal segment (coronal, middle, apical) in each half of a split root specimen (Fig. 4). No attempt was made to distinguish between residual sealer and gutta-percha or Resilon. The outlines of the corresponding canal wall segments were also traced, in order to calculate the canal surface area. Residue areas were expressed as percentage of canal surface area. Combining the root halves for each specimen, the mean residue percentage

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Figure 3 Composite photomicrograph of the coronal, middle and apical segments of half a root specimen after retreatment to apical size 45. Canal was filled with the Epiphany System. Note areas covered with root-filling residue.

Figure 4 Composite computer image of traced residue in the coronal, middle and apical segments of half a root specimen after retreatment to apical size 45. Same specimen as in Fig. 3.

value for canal segments and the whole canal was calculated for the subgroups and groups, after each end-point of the retreatment procedure (size 45 and 55). The images previously obtained from all canals prior to root filling were used to ascertain that only residue from the retreatment procedure was recorded and any debris that was present prior to root filling and still appeared after retreatment was not recorded in the final assessment.

Analysis

A series of independent *t*-tests were used to analyse the differences in residue percentage values between the

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experimental and control groups, the two subgroups and apical enlargement to size 45 and 55. The differences in the residue values amongst the coronal, middle and apical segments were analysed with repeated measures ANOVA and Bonferroni-adjusted pairwise comparisons. The difference in retreatment time between the experimental and control groups as well as the subgroups were analysed with two-way ANOVA. The level of significance for all the above statistical tests was set at $P < 0.05$.

Results

Residue of the root-filling materials was observed in all the specimens regardless of the root-filling material or retreatment technique used. The residue percentage values in the experimental and control groups are related to the retreatment technique subgroups and canal levels in Table 1. The mean total residue for the experimental group was significantly higher ($P = 0.01$) than for the control group, both with solvent ($9.2 \pm 1.8\%$ vs. $4.3 \pm 1.0\%$) and without solvent (13.3 ± 2.1 vs. $7.2 \pm 0.9\%$). The same pattern and significance was observed at each canal level. The highest residue value was consistently recorded in the apical canal level, with significantly less ($P < 0.01$) residue in the middle level, and the least residue in the coronal level. The difference between the middle and coronal levels was not significant ($P = 0.07$) only in the control group. In both groups, the total residue values were significantly higher ($P < 0.01$) in the nonsolvent subgroup. The same pattern and significance were observed in the apical canal level in both groups, and in the middle canal level in the experimental group. Similar distribution of results and significant differences were observed when absolute residue surface area values (mm^2) were compared, rather than the residue percentage values (results not shown).

Table 2 Root-filling residue in the apical third of root canals filled with the Epiphany System or gutta-percha and AH Plus sealer, after retreatment with apical enlargement to size 45 or 55

Group	Retreatment technique	Mean (SD) residue percentage		
		Size 45	Size 55	*P*-value
Experimental (Epiphany System)	Solvent	22.5 (4.4)	18.6 (4.2)	<0.01
	No solvent	32.5 (4.0)	26.2 (4.0)	<0.01
Control (Gutta-percha, AH Plus)	Solvent	11.0 (2.9)	5.9 (3.0)	<0.01
	No solvent	21.2 (2.8)	16.4 (3.9)	<0.01

Table 2 represents the residue values at the apical canal level in relation to apical enlargement. Significantly lower ($P < 0.01$) residue values were consistently observed after enlargement to size 55 than to size 45 (Fig. 5).

The time required to reach working length with size 45, 0.04 taper instruments is summarized in Table 3. Retreatment time in the experimental group was significantly longer ($P < 0.0001$) than in the control group. In both groups, retreatment time in the nonsolvent subgroup was significantly longer ($P < 0.0001$) than in the solvent subgroup. Retreatment was the slowest in the experimental group without solvent (mean 13 min, 8 s) and the fastest in the control group with solvent (mean 5 min, 7 s).

Discussion

The experimental protocol developed for this study was a modification of previously used models for studying retreatment efficacy. The modification was inspired by

Table 1 Root-filling residue in root canals filled with the Epiphany System or gutta-percha and AH Plus sealer, after retreatment with or without solvent. Apical enlargement to size 45

Group	Canal level	Mean (SD) residue percentage		
		Solvent	No solvent	*P*-value
Experimental (Epiphany System)	Coronal	1.9 (1.8)	2.2 (1.7)	0.62
	Middle	5.5 (2.2)	8.4 (2.8)	<0.01
	Apical (45)	22.5 (4.4)	32.5 (4.0)	<0.01
	Total 1	**9.2 (1.8)**	**13.3 (2.1)**	**<0.01**
Control (Gutta-percha, AH Plus)	Coronal	0.8 (0.8)	0.8 (0.9)	0.95
	Middle	2.5 (1.5)	2.2 (1.7)	0.66
	Apical (45)	11.0 (2.9)	21.2 (2.8)	<0.01
	Total 2	**4.3 (1.0)**	**7.2 (0.9)**	**<0.01**
***P*-value (Total 1 vs. Total 2)**		**0.01**	**0.01**	

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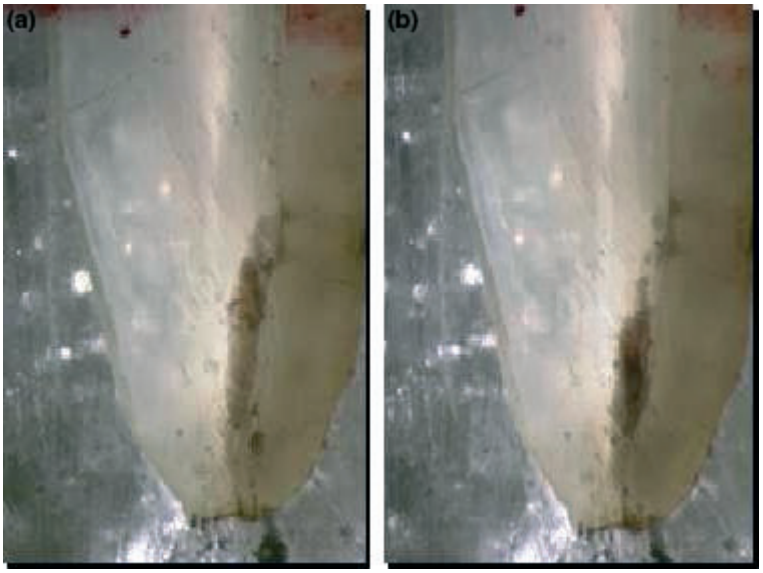

Figure 5 Photomicrographs of the apical segment of half a root specimen showing root-filling residue after enlargement to size 45 (a) and size 55 (b). Canal was filled with the Epiphany System.

Table 3 Time required to complete retreatment with or without solvent, in canals filled with the Epiphany System or gutta-percha and AH Plus sealer

	Mean (SD) retreatment time (min′; sec″)		
Group	Solvent	No solvent	*P*-value
Experimental (Epiphany System)	9′4″ (0.5″)	13′8″ (0.7″)	<0.0001
Control (Gutta-percha, AH Plus)	5′7″ (0.6″)	7′6″ (0.6″)	<0.0001

the model of horizontal assembly and disassembly of roots for assessment of shaping characteristics, developed by Bramante *et al.* (1987). The present assembly–disassembly protocol was adapted to allow assessment of possible residue reduction by extensive apical enlargement. This aspect of retreatment has not been previously assessed, possibly because of unavailability of a suitable model. The reversible model also allowed the exclusion of areas covered with debris before canals were filled.

Assessment of root-filling residue in previous studies has been completed with a variety of outcome measures. Noninvasive assessment has been carried out radiographically (Ferreira *et al.* 2001, Masiero & Barletta 2005) or by clearing the roots (Schirrmeister *et al.* 2006a,b). The cleared roots were viewed in buccolingual and mesiodistal directions, and the filling residue quantified with an image analyzer program (Schirrmeister *et al.* 2006a,b). In the majority of studies, however, roots were split vertically after retreatment to measure the amount of residue (Wilcox *et al.* 1987, Wilcox 1989, Friedman *et al.* 1992, 1993, Moshonov *et al.* 1994, Sae-Lim *et al.* 2000, Ezzie *et al.* 2006, de Oliveira *et al.* 2006). In the pioneering studies (Wilcox *et al.* 1987, Wilcox 1989) the split canal walls were photographed and residue-covered areas were manually traced on the projected images. Recently, the residue surface area was measured with image analysis software (de Oliveira *et al.* 2006) applied to images captured with a digital camera with low magnification. In other studies (Friedman *et al.* 1992, 1993, Moshonov *et al.* 1994, Sae-Lim *et al.* 2000, Ezzie *et al.* 2006), the assessment was carried out with the aid of the dissecting microscope and qualitative rating of the amount of residue. All the above methods have specific limitations, thus quantification of residue is not precise. The assessment method used in the present study, with images captured under high magnification and traced with a scan program, may have improved the accuracy of assessment, even though it too had limitations. The amount of residue was expressed in relation to the canal surface area, to provide a perspective of the extent of the problem, as in previous studies where residue was rated qualitatively as percentage of canal wall surface (Masiero & Barletta 2005, de Oliveira *et al.* 2006).

The root canals in this study were filled using lateral condensation, similar to most previous studies concerning retreatment efficacy (Wilcox *et al.* 1987, Wilcox 1989, Sae-Lim *et al.* 2000, de Oliveira *et al.* 2006). AH

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Plus was selected as the control, as in previous studies (Friedman *et al.* 1992, 1993, Moshonov *et al.* 1994) that assessed the retreatment efficacy of a glass-ionomer cement sealer, and the most recent studies on the retreatment efficacy of the Epiphany System (Ezzie *et al.* 2006, de Oliveira *et al.* 2006, Schirrmeister *et al.* 2006b). This widely used epoxy resin-based sealer adheres to dentine, making it more resistant to retreatment than nonadhesive sealers (Wilcox *et al.* 1987, Friedman *et al.* 1992). In this respect it was considered a fair comparison with the Epiphany System.

Different methods have been applied in previous studies to remove the root-filling materials from canals. These include use of hand files (Wilcox *et al.* 1987, Friedman *et al.* 1992, Ezzie *et al.* 2006, Schirrmeister *et al.* 2006b), ultrasonic files (Wilcox 1989, Friedman *et al.* 1992, 1993, Moshonov *et al.* 1994), engine-driven instruments (Bramante & Betti 2000, Sae-Lim *et al.* 2000, Ferreira *et al.* 2001, Masiero & Barletta 2005, Ezzie *et al.* 2006, de Oliveira *et al.* 2006, Schirrmeister *et al.* 2006a,b) and laser irradiation (Viducic *et al.* 2003). Often Gates-Glidden drills were used in the coronal portion of the canal, and gutta-percha was softened by means of solvents (Wilcox *et al.* 1987, Wilcox 1989, Friedman *et al.* 1992, 1993, Moshonov *et al.* 1994, Sae-Lim *et al.* 2000, Ferreira *et al.* 2001, Masiero & Barletta 2005, Ezzie *et al.* 2006, de Oliveira *et al.* 2006, Schirrmeister *et al.* 2006a) or heat (Wilcox *et al.* 1987, Wilcox 1989, Ezzie *et al.* 2006). In the present study, removal of the root filling followed current retreatment strategies. Gates-Glidden drills, recommended for gutta-percha removal at the canal orifice level (Friedman *et al.* 1990), were used in the coronal 2 mm of the canals. This step facilitates access to the more apical portions of canals, and it provides a receptacle for the placement of solvent. Chloroform was the solvent selected for this study because it effectively dissolves gutta-percha (Tamse *et al.* 1986) and because it is recommended by the manufacturer for retreatment of the Epiphany System. The remaining root filling was removed with engine-driven instruments, as they have been shown to efficiently and safely remove gutta-percha and sealer from the canals (Bramante & Betti 2000, Sae-Lim *et al.* 2000, Ferreira *et al.* 2001, Masiero & Barletta 2005, Ezzie *et al.* 2006, de Oliveira *et al.* 2006, Schirrmeister *et al.* 2006a,b). The K3 0.04 taper instruments were selected to match the shape of the filled canals that were cleaned and shaped with the same instruments. Also, the design of the K3 instruments is helpful in drawing out debris coronally (Koch & Brave 2002), and their efficiency in removal of gutta-percha and Resilon was confirmed in a recent study (de Oliveira *et al.* 2006). Rotation speed was limited to 350 rpm, in accordance with the recommended use of K3 instruments (Koch & Brave 2002). Although it was recognized that increased rotation speed would expedite the retreatment procedure, it was considered that the higher speed would increase the risk of canal transportation and instrument fracture. These risks would render the higher rotation speed less applicable to clinicians than the safer, slower rotation speed. The slower rotation speed was also used in a recent study (de Oliveira *et al.* 2006) for the same reasons. As a final step, canals were apically enlarged with 0.02 taper hand files, to simulate how most clinicians would use larger size instruments.

The present study results indicated that neither material could be removed completely from the canal walls. This observation was consistent with those of previous studies on retreatment efficacy in which various root-filling materials and retreatment techniques were used (Wilcox *et al.* 1987, Wilcox 1989, Friedman *et al.* 1992, 1993, Moshonov *et al.* 1994, Bramante & Betti 2000, Sae-Lim *et al.* 2000, Ferreira *et al.* 2001, Viducic *et al.* 2003, Masiero & Barletta 2005, Ezzie *et al.* 2006, de Oliveira *et al.* 2006, Schirrmeister *et al.* 2006a,b). The greatest amount of residue consistently remained in the apical segment of the canals, again corroborating the results in previous studies (Wilcox *et al.* 1987, Wilcox 1989, Friedman *et al.* 1992, 1993, Moshonov *et al.* 1994, Bramante & Betti 2000, Sae-Lim *et al.* 2000, Ferreira *et al.* 2001, Masiero & Barletta 2005, Ezzie *et al.* 2006, de Oliveira *et al.* 2006, Schirrmeister *et al.* 2006a,b).

Removal of the root filling in canals filled with the Epiphany System was less efficacious than in canals filled with gutta-percha and AH Plus sealer, as demonstrated by the greater amount of residue and the longer time required for retreatment. The greater resistance of Epiphany sealer to removal could be explained by its bonding to the dentine surface, as opposed to only adhesion of the AH Plus. However, in recent studies (Ezzie *et al.* 2006, de Oliveira *et al.* 2006, Schirrmeister *et al.* 2006b) retreatment of canals filled with the Epiphany System left less residue than retreatment of gutta-percha and AH Plus sealer, and took less time (Ezzie *et al.* 2006, de Oliveira *et al.* 2006) or comparable time (Schirrmeister *et al.* 2006b). The contrasting results of the present and previous studies may be attributed to several critical differences in design and methodology, as described below.

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The root fillings in the previous studies (Ezzie *et al.* 2006, de Oliveira *et al.* 2006, Schirrmeister *et al.* 2006b) were allowed to set for only 1–3 weeks in an aerobic environment, compared with 8 weeks in an anaerobic environment in the present study. It has been suggested (Nielsen *et al.* 2006) that the Epiphany sealer sets in 30 min in an anaerobic environment, but in presence of air setting takes a week and an uncured layer remains on the surface (Nielsen *et al.* 2006). The slow setting of the Epiphany System in an *in vitro* aerobic environment raises potential concerns about the complete setting of the material in the previous studies (Ezzie *et al.* 2006, de Oliveira *et al.* 2006, Schirrmeister *et al.* 2006b). A pilot test conducted prior to this study showed that the Epiphany System was not set after 2 weeks in an aerobic environment, whilst setting was complete after 8 weeks of anaerobic incubation. If the Epiphany System root fillings in the previous studies (Ezzie *et al.* 2006, de Oliveira *et al.* 2006, Schirrmeister *et al.* 2006b) were not fully set, they would be considerably easier to retreat than set materials, and there would be minimal residue left of the unset sealer. In addition, the canals in these studies (Ezzie *et al.* 2006, de Oliveira *et al.* 2006, Schirrmeister *et al.* 2006b) were retreated to two sizes larger than the apical size before filling, reducing the amount of residue even further, as shown in the present study.

In two of the studies (de Oliveira *et al.* 2006, Schirrmeister *et al.* 2006b) Gates-Glidden drills were taken as deep as 5–6 mm into the canals, compared with 2 mm in the present study. The deep penetration with Gates-Glidden drills left approximately 4–5 mm of root filling to be removed, which may not be challenging, and insufficient for comparison of retreatment efficacy. In the coronal 6 mm, the Gates-Glidden drills would have removed all of the root-filling material and an extensive amount of surrounding root dentine, leaving a dentine surface free of any root-filling residue. Furthermore, the widening of the middle and coronal canal space would have facilitated the retreatment in the apical segment in a way that is inconsistent with clinical practice. Clinically, Gates-Glidden drills can only be carried deep into canals in straight roots. In teeth with narrow curved roots, clinicians should avoid taking these drills more than 2–3 mm apically, to avoid stripping perforation of the canal wall.

In two of the studies (Ezzie *et al.* 2006, Schirrmeister *et al.* 2006b) the root canals were filled using vertical compaction, as opposed to lateral compaction in the present study. The amount of sealer used in conjunction with vertical compaction is less than with lateral compaction; therefore, there is less sealer that has to be removed. Furthermore, in two of the previous studies (Ezzie *et al.* 2006, de Oliveira *et al.* 2006,) chloroform was added to canals several times during retreatment. In contrast, in the present study a small amount of chloroform was used once, at the start of retreatment with rotary instruments.

In one study (de Oliveira *et al.* 2006) the net retreatment time was calculated excluding the time to change files and irrigate the canal. The retreatment time ranged from 2 to 4 min. In the other two studies (Ezzie *et al.* 2006, Schirrmeister *et al.* 2006b) the retreatment time was in the range of 3–5 min, but how it was recorded was not specified. In contrast, the total retreatment time was recorded in the present study, including irrigation and instrument change. It ranged from approximately 9 to 13 min.

Retreatment of the Epiphany System was enhanced by the use of chloroform as recommended by the manufacturer. The use of chloroform both reduced the time of retreatment and the amount of residue. Similarly, the retreatment efficacy of gutta-percha and AH Plus was enhanced by the use of the solvent. Chloroform is widely used as a solvent for gutta-percha (Tamse *et al.* 1986), even though it is locally toxic in contact with periradicular tissues, and it is hepatotoxic and nephrotoxic (Barbosa *et al.* 1994). In spite of these unfavourable properties, chloroform can be used safely in retreatment procedures, and it is not banned in such applications (Margelos *et al.* 1996, Chutich *et al.* 1998). Nevertheless, it may be preferred in specific patients to avoid its use. Therefore, it is important to note that retreatment of the Epiphany System was found to be possible even without the use of solvent, as in a previous study (Schirrmeister *et al.* 2006b).

Apical enlargement by two sizes beyond the canal dimension at the time of root filling resulted in a significant reduction in the amount of residue in the apical 3 mm of the canal space. Considering the limitations of removing root-filling materials from canal walls, extensive enlargement may be the only clinical means available to improve retreatment efficacy. This finding suggests that further enlargement of at least another two sizes may enhance canal cleanliness beyond what was achieved in this study. Enlarging canals to large apical sizes is generally possible with the use of 0.02 taper nickel–titanium hand files, particularly when the coronal two-thirds of the canal were enlarged with tapered instruments as in this study. Nevertheless, extensive apical enlargement may be associated with a risk of transportation; therefore, it should always be

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considered in view of the expertise and skill of the clinician, as well as the specific canal and root anatomy.

Orthograde retreatment aims at elimination of bacteria colonizing the canal walls and dentinal tubules. In this regard, patches of root-filling residue may be considered to shelter bacterial colonies. The residue may be blocking sections of canal walls and prevent access of antimicrobial irrigants to these sites. Thus, the more residue remains after retreatment, the more bacteria may survive that may jeopardize the outcome of the retreatment procedure. This concern is greatest in the apical segment where most residue is found (Wilcox *et al.* 1987, Wilcox 1989, Friedman *et al.* 1992, 1993, Moshonov *et al.* 1994, Bramante & Betti 2000, Sae-Lim *et al.* 2000, Ferreira *et al.* 2001, Masiero & Barletta 2005, Ezzie *et al.* 2006, de Oliveira *et al.* 2006, Schirrmeister *et al.* 2006a,b); therefore, thorough elimination of root-filling residue in the apical segment is clinically important. As suggested by the present study results, extensive apical enlargement may improve the clinicians' ability to reduce apical residue.

Conclusion

Root fillings performed with the Epiphany System were retreatable with or without use of chloroform as a solvent. The retreatment was less efficacious than that of gutta-percha and AH Plus sealer, with longer time required to complete retreatment and more material residue left adhering to the canal walls. The most residue was present in the apical segments of canals, but removal of this residue was enhanced by apical enlargement beyond the diameter of the canal before retreatment.

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