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Filling of artificial lateral canals and microleakage and flow of five endodontic sealers

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Abstract

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Aim To evaluate the flow characteristics of AH Plus, Epiphany Root Canal Sealant, Endométhasone, Pulp Canal Sealer (EWT) and Sealapex and their ability to fill artificial lateral canals and prevent microleakage.

Methodology Flow of the sealers was analysed using the American Dental Association (ADA) 57 and the International Standards Organization (ISO) 6876 specifications. Two lateral canals were produced in the middle and apical third of 64 roots using 0.1 mm cylindrical drills. Lateral condensation of gutta-percha or Resilon and one or other of the sealers were used to fill the root canals. Buccal-lingual digital radiographs were exposed. After the sealer had set, the roots were immersed in Indian ink and cleared in methyl salicylate. The extent of filling and dye penetration were measured on the buccal and lingual root surfaces under 30× magnification with a stereoscope.

Results AH Plus, Epiphany and Pulp Canal Sealer (EWT) complied with ADA 57 and ISO 6876 specifications. Sealapex complied with the ADA 57 specification but not with ISO 6876. Endométhasone did not comply with either specification. Filling of lateral canals was similar for the five sealers tested. Dye leakage demonstrated that AH Plus, Epiphany and Sealapex permitted less leakage than Pulp Canal Sealer (EWT) ($P < 0.05$).

Conclusions All the sealers flowed into the 0.1 mm artificial lateral canals. AH Plus, Epiphany and Sealapex allowed less linear leakage than Pulp Canal Sealer (EWT). The flow of Endométhasone did not comply with either ADA 57 or ISO 6876 specifications and Sealapex did not comply with ISO 6876.

Keywords: artificial lateral canal, filling, dye leakage, flow, root canal sealer.

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Introduction

An endodontic sealer must have several properties to be considered suitable. Flow is important as it reflects its ability to penetrate into small irregularities and ramifications of the root canal system and dentinal tubules (Grossman 1976, Siqueira *et al.* 1995, Weis *et al.* 2004). Moreover, flow along with the sealer's antimicrobial effectiveness may aid the disinfection of the root canal system (Siqueira *et al.* 2000, Saleh *et al.* 2004).

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Root canal ramifications, such as lateral, secondary and accessory canals can establish connection between the main root canal and periodontal ligament, as well as the apical foramen (De Deus 1975). Several authors described that localized periodontal problems might be associated with necrotic and infected root canal ramifications (Kirkham 1975, Weine 1984, Barkhordar & Stewart 1990) highlighting the importance of the capacity of the endodontic sealer to flow into these irregularities. Despite the significance of this physical property, the relationship between flow and its ability to penetrate narrow root canal ramifications has not been investigated (Venturi *et al.* 2003).

Extracted human teeth with confirmed root canal ramifications have been used to evaluate various types of sealers and filling techniques for their ability to fill the root canal system (Clark & ElDeeb 1993, Karagoz-Kucukay 1994, Venturi *et al.* 2003). Due to the difficulty of obtaining human teeth with natural ramifications to allow comparisons, several authors have produced artificial canal ramifications in resin blocks (Himel & Cain 1993, Reader *et al.* 1993, Dulac *et al.* 1999, Silver *et al.* 1999), which resemble those found in natural teeth (Goldberg *et al.* 2001, 2002, Pecora *et al.* 2002, Moraes *et al.* 2004). Despite the ease of developing narrow ramifications in resin blocks, their surface texture and condition could influence the flow properties of gutta-percha and sealer (Dulac *et al.* 1999) and thus, there are limitations of using epoxy blocks instead of natural teeth (Reader *et al.* 1993).

Gutta-percha thermoplastic techniques were more efficient in filling lateral canals prepared in human teeth than the lateral condensation technique (Goldberg *et al.* 2001) and the use of calcium hydroxide dressings has been reported to reduce the quality of fillings within root canal ramifications (Goldberg *et al.* 2002). However, work to date has only illustrated which sealer or filling technique can fill root canal ramifications and doubt remains about the quality of the seal they produce (Weine 1984). Apical and coronal seals and the prevention of microleakage have been studied using several methodologies (Madison & Wilcox 1988, Wu & Wesselink 1993, Lucena-Martin *et al.* 2002, Zaia *et al.* 2002). However, the sealing ability of sealers has not been tested exclusively in natural or artificial lateral canals.

The aim of this study was to evaluate the flow characteristics of AH Plus, Epiphany Root Canal Sealant, Endométhasone, Pulp Canal Sealer (EWT) and Sealapex and to determine their ability to fill artificial lateral canals and prevent microleakage.

Materials and methods

Root canal sealers

Five endodontic sealers were used: two resin-based sealers AH Plus (Dentsply DeTrey, Konstanz, Baden-Württemberg, Germany) and Epiphany Root Canal Sealant (Pentron Clinical Technologies, Wallingford, CT, USA); two zinc oxide-eugenol based sealers Endométhasone (Septodont, Saint-Maur-Dês-Fossés, France) and Pulp Canal Sealer EWT (Kerr Corporation, Orange, CA, USA) and one sealer containing calcium hydroxide Sealapex (SybronEndo, Glendora, CA, USA). All materials were prepared according to manufacturers' instructions.

Flow test

Two international standards were used to conduct the flow test: American Dental Association (ADA) no. 57 (American National Standards/American Dental Association 1983) and International Standards Organization (ISO)-6876 (International Organization for Standardization 2001).

According to the ADA 57 specification, 0.5 mL of the material was mixed and placed on the centre of a glass plate using a graduated syringe (Becton Dickinson, Curitiba, PR, Brazil). At 180 s (±5 s) after initiating mixing, another glass plate was placed centrally on top of the sealer, followed by a weight giving a total mass of 120 g (±2 g). Ten minutes after initiating the mixing, the weight was removed and the maximum and minimum diameters of the compressed discs of sealers were measured. Two conditions were necessary to validate the tests: the difference between the maximum and minimum diameters could not exceed 1.0 mm and the compressed disc should have uniform shape. If these conditions were not met, the test was repeated. Three determinations were carried out and the mean value was calculated to the nearest millimetre. The disc diameter should be at least 25 mm. The only differences between ADA and ISO standards are the volume analysed and the minimum diameter of spread, thus to test the ISO 6876 specification, the volume of sealer was 0.05 mL (±0.005 mL) and each compressed disc should have a diameter not <20 mm.

Filling and microleakage of artificial lateral canals

Sixty-four recently extracted human maxillary anterior teeth were selected with the approval of the Human Ethical Committee of the Piracicaba Dental School, State University of Campinas. The crowns of the teeth were removed using a low-speed diamond disc under running water and a standard length of 15 mm was achieved for every root. A buccal-lingual digital radiograph (Schick Technologies Inc., Long Island, NY, USA) was exposed and teeth with natural lateral canals were discarded. The teeth were randomly divided into five groups according to the sealer employed: G1, AH Plus; G2, Epiphany; G3, Endométhasone; G4, Pulp Canal Sealer (EWT); and G5, Sealapex.

The ramifications produced were called lateral canals, independent of the root canal third in which they appeared. Two artificial lateral canals, one in the middle and the other in the apical third, were prepared perpendicular to the longitudinal axis of the teeth using

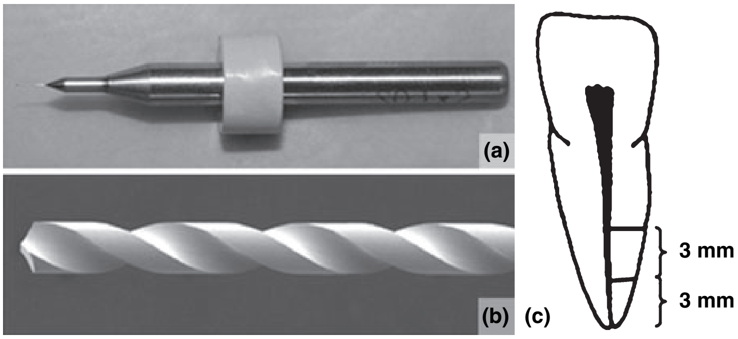

Figure 1 (a) 0.1 mm drill used to make lateral canals in experimental teeth, (b) SEM photomicrograph of drill active part (100× magnification), (c) the scheme demonstrates how the lateral canals were performed 3 mm from the root apex (apical third) and 6 mm from the root apex (middle third).

0.10 mm cylindrical drills (Union Tool Europe S.A., Marin, Neuchâtel, Switzerland) (Fig. 1) in a machining centre (Discovery-Romi, Santa Bárbara d'Oeste, SP, Brazil), which created the perforations. The penetration of the drill into the root canal was checked by introducing a size 06 K-file (Dentsply Maillefer, Ballaigues, Switzerland) into the perforations and another digital radiograph was exposed. If the file did not penetrate into the main root canal, the tooth was discarded.

The coronal and middle thirds of the root canals were shaped with size 3 and 2 Gates-Glidden burs (Dentsply Maillefer). The working length was established by subtracting 1 mm from the measurement acquired by placing a size 10 K-file (Dentsply Maillefer) into the root canal until the tip could be seen at the foramen. The apical third was prepared up to a size 45 K-file (Dentsply Maillefer); after every change of bur or file the canals were irrigated with 1 mL of 2.5% sodium hypochlorite. Following canal preparation, 3 mL of 17% EDTA was used to remove the smear layer, then 3 mL of 2.5% sodium hypochlorite and 3 mL of saline solution were used as final irrigants. Each canal was dried with paper points.

Before root canal filling, the teeth were mounted in alginate blocks (Dentsply, Petrópolis, RJ, Brazil) to confine the sealer after it had flowed through the artificial lateral canals, in an attempt to simulate the periodontal ligament. In all groups, except G3, the sealer was introduced into the root canals with a size 40 spiral Lentulo (Dentsply Maillefer). For the lateral condensation technique: a size 45 standardized gutta-percha cone (Tanari, Manacapuru, AM, Brazil) coated with sealer was fitted as a master cone. Lateral compaction was performed with 25 and 30 finger spreaders (Dyna, Bourges, France) and B7 and B8 accessory cones (Tanari) were introduced to fill the root canal. Excess gutta-percha was removed with a heated instrument and cold pluggers were used to vertically condense the coronal gutta-percha. In group 2, a paper point coated with Primer was introduced into the canal to its working length. Another paper point was then used to dry the canal and the filling was completed with Resilon cones and Epiphany Root Canal Sealant (Pentron Clinical Technologies), using the lateral condensation technique.

After being filled, all groups of teeth, except G2, were maintained for 48 h at high humidity and 37 °C to allow the sealers to set. Group 2 remained at high humidity and 37 °C for 14 days. The alginate blocks were then removed and digital radiographs were taken. The images were analysed at 100% magnification using the colour inversion facility within the Computed Dental Radiography (CDR) software (Schick Technologies Inc.). The total length of the lateral canal and its filling by sealer were measured with this software and the measurements converted to percentage of canal filled.

The external root surface was sealed with two layers of red nail varnish, except for the area over the lateral canals. Four unfilled teeth were used as positive and negative microleakage controls. The positive control was sealed like the other teeth and the negative control was sealed completely including the lateral canal orifices. All teeth were then immersed in Indian ink (Royal Talens, Apeldoorn, The Netherlands), submitted to vacuum for 30 min and stored in the ink for 24 h. Following exposure to the dye, the teeth were rinsed in tap water and the nail varnish removed completely with a scalpel. The teeth were then decalcified in 5% hydrochloric acid for 72 h and cleared in methyl salycilate according to Zaia *et al.* (2002).

The extent of filling, dye penetration and the total length of lateral canals were measured on the buccal and lingual root surfaces, under 30× magnification with a stereoscope (Lambda Let 2, ATTO Instruments Co., Hong Kong, China) and ImageLab 2.3 software

(University of São Paulo, São Paulo, SP, Brazil). These measurements were converted to percentages.

Data were statistically analysed using Kruskal–Wallis, Dunn and Wilcoxon tests using BioEstat 3.0 software (CNPq, Brasília, DF, Brazil). Differences of $P < 0.05$ were considered to be significant. For the microleakage data, all lateral canals were considered together independent of the third they were located in.

Results

Flow test

The flow of sealers is presented in Table 1. Only Endométhasone did not comply with the ADA 57 specification. The others presented higher flow than the minimum required for this test. Sealapex and Endométhasone did not reach the minimum flow for compliance with ISO 6876. While Sealapex was close to complying with this specification, Endométhasone achieved significantly lower flow than the minimum required.

Filling and microleakage of artificial lateral canals

The percentage of canals filled with sealers varied with some lateral canals being full, while others were partially filled or unfilled (Fig. 2). The radiographic analysis failed to identify filled lateral canals in 8% of specimens, that were visible using the clearing technique (Fig. 3). Thus, the parameters for establishing the filling results were based on the clearing technique and dye microleakage, whereas partially filled or unfilled lateral canals were identified radiographically. Unfilled lateral canals were defined as those presenting no radiographic image, no presence of sealer in the clearing technique and with positive dye microleakage. Filled lateral canals were those with positive or negative radiographic images but with sealer present in the clearing technique.

The percentages of filling of lateral canals were consistent for all sealers tested, independent of the root canal third analysed. Unfilled or partially filled lateral canals were detected in few cases. No statistically significant differences were found between the groups for the middle and apical thirds. The results of analysis between the root canal thirds for each tested sealer did not show any differences ($P > 0.05$) (Table 2).

Table 1 Flow of each endodontic sealer measured against ADA 57 and ISO 6876 specifications

Sealers	57 ADA (mm)	6876 ISO (mm)
AH Plus	43	22
Epiphany Root Canal Sealant	36	28
Endométhasone	20	11
Pulp Canal Sealer (EWT)	44	23
Sealapex	31	19

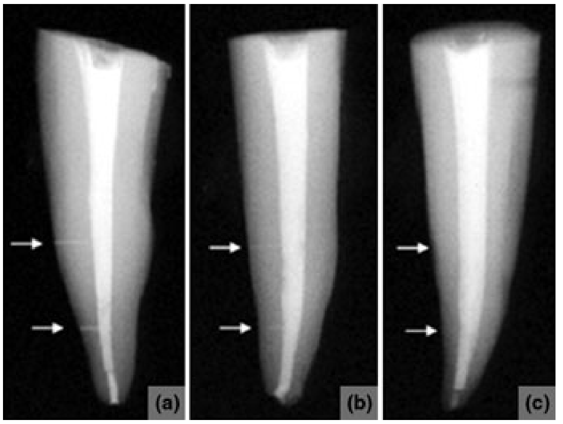

Figure 2 Digital radiographic images demonstrating: (a) complete lateral-canal fillings, (b) complete lateral-canal filling in the middle third and partial filling in the apical third, (c) unfilled lateral canals.

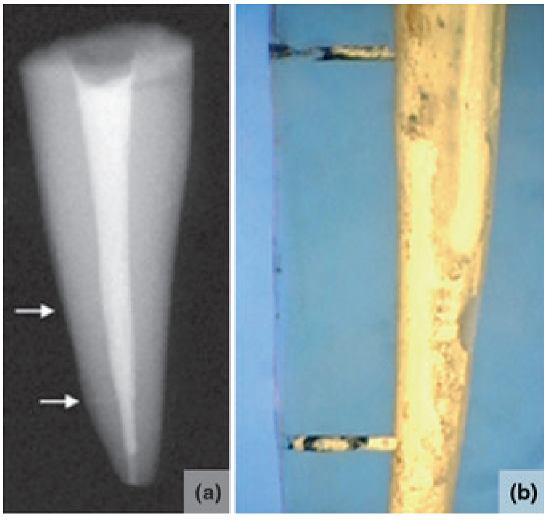

Figure 3 (a) Digital radiographic image demonstrating no filling in the middle third and complete lateral-canal filling in the apical third, (b) cleared-tooth image illustrating a partially-filled middle lateral canal and a completely filled apical lateral canal, both canals being filled with Endométhasone with different microleakage levels.

Table 2 Medians of filling percentages for each endodontic sealer and *P*-comparison values between root canal thirds for each sealer

Sealer	Apical third		Middle third		*P*-value*
	Medians	Variation interval (%)	Medians	Variation interval (%)	
AH Plus	100	100–100	100	0–100	0.1797
Epiphany Root Canal Sealant	100	46–100	100	38–100	1.0000
Endométhasone	100	0–100	100	0–100	0.6858
Pulp Canal Sealer (EWT)	100	0–100	100	16–100	0.6858
Sealapex	100	70–100	100	25–100	0.2850

Columns show no statistically significant difference – Kruskal Wallis test ($P > 0.05$).
*Wilcoxon test.

The clearing technique identified 18 natural root canal ramifications in 13 teeth: two lateral canals, 14 secondary canals, one accessory canal and one recurrent canal. The diameters of these canals ranged between 0.12 and 0.26 mm, except three that had a diameter smaller than 0.10 mm. Ten root canal ramifications were completely filled, five partially filled and three were unfilled (Fig. 4).

All sealers, except Pulp Canal Sealer EWT, were able to seal some artificial lateral canals with no microleakage. All of them allowed partial or total microleakage (Fig. 5). AH Plus, Epiphany and Sealapex had statistically significantly lower percentages of dye microleakage than Pulp Canal Sealer EWT ($P < 0.05$). Endométhasone did not differ significantly from the other sealers ($P > 0.05$) (Table 3).

The control teeth demonstrated positive microleakage through the lateral canals that did not receive nail varnish and no microleakage was found in the sealed lateral canals.

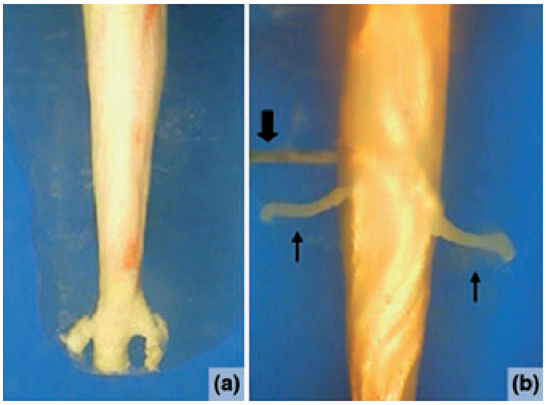

Figure 4 (a) Natural secondary canal (0.23 and 0.26 mm of diameters) filled by AH Plus sealer (amplification 20×), (b) two natural lateral canals (arrows showing 0.13 and 0.12 mm diameters) and an artificial lateral canal (wide arrow showing a 0.10 mm diameter) filled by Epiphany Root Canal Sealant (amplification 25×).

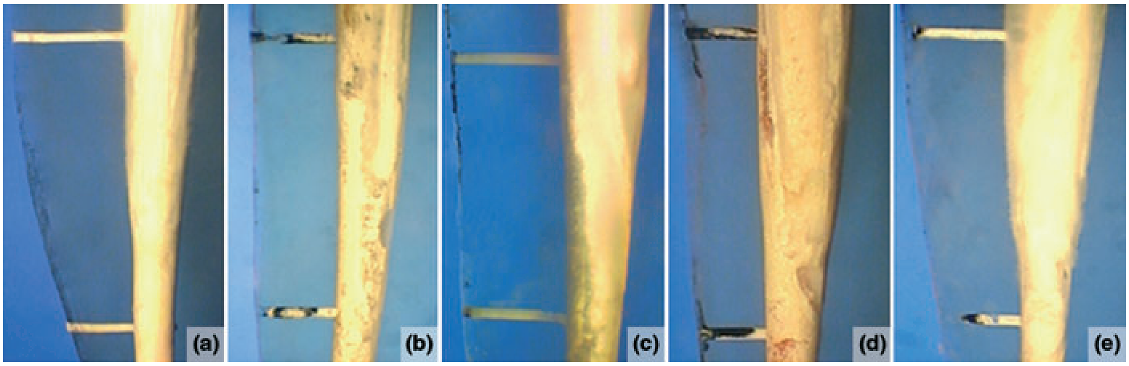

Figure 5 Cleared teeth images. (a) lateral canals completely filled by AH Plus without any dye microleakage, (b) middle lateral canal filled partially and apical lateral canal completely filled by Endométhasone with different microleakage levels, (c) lateral canals completely filled by Epiphany Root Canal Sealant without any dye microleakage, (d) lateral canals completely filled by Pulp Canal Sealer EWT with extensive dye microleakage, (e) middle lateral canal completely filled with no microleakage and apical lateral canal partially filled by Sealapex with a small amount of microleakage.

Table 3 Medians of dye microleakage percentages for each endodontic sealer

Sealers	Median	Minimum values (%)	Maximum values (%)	Rank
AH Plus	0	0	100	34.00[b]
Epiphany Root Canal Sealant	0	0	100	44.92[b]
Endométhasone	17	0	100	51.29[ab]
Pulp Canal Sealer (EWT)	70	29	100	73.39[a]
Sealapex	21	0	100	43.50[b]

Different letters in superscript mean statistically significant difference – Kruskal Wallis and Dunn tests ($P < 0.05$).

Discussion

Flow was different between sealers and when tested using the ADA or ISO specifications (Table 1). The composition of the sealers seems to be the main factor related to its flow characteristics. Thus, the powder particle size in powder/liquid sealers (Weisman 1970), as well as the sealer's constituents and setting time (Grossman 1976), appears to interfere with flow. Nevertheless, there is little information to relate the composition of paste/paste or resin-based sealers to their flow properties.

The presence of resin in Pulp Canal Sealer EWT's composition and in the two resin-based sealers could explain their better flow. Conversely, the absence of resin in Endométhasone could explain its poor flow. Endométhasone was the only sealer that did not comply with either of the two specifications. Grossman (1982) reported that a resin additive in zinc oxide–eugenol-based sealers provided plasticity and improved flow.

Endométhasone did not comply with the two international specifications and Sealapex did not comply with the ISO 6876 specification. All sealers demonstrated high percentages of filling when both canal thirds were analysed (Table 2), emphasizing that all sealers tested could fill root canal ramifications. These results illustrate that the flow required by ADA 57 and ISO 6876 specifications did not correlate with the capacity of the sealer to properly fill the artificial ramifications.

The 0.1 mm drills produced regular canals having similar internal and external diameters of the root canal surfaces (Fig. 6). Group 2 remained for 14 days at 37 °C after root canal filling. Epiphany is a dual-curable monomer-based sealer that needs an initiator to promote monomer conversion. The amount of initiator in the sealer is proportional to resin contraction. Epiphany, probably, has a small amount of initiator to avoid contraction and to allow a longer working time. Therefore, small amounts of initiator require more time to set. When a composite is heated, there is an increase in monomer conversion (Daronch *et al.* 2005). These two facts explain why it was necessary to keep this sealer for 14 days at 37 °C to set under laboratory conditions (Shipper *et al.* 2004, Oliveira *et al.* 2006).

The mean percentage of lateral-canal fillings for all sealers was 88% using the lateral condensation technique. The comparison of the results obtained from the radiographic and clearing analyses revealed that approximately 8% of the filled lateral canals did not appear on radiographic images. Thus, radiographs do not only fail to demonstrate the presence of ramifications in the root canal system on preoperative images (Altman *et al.* 1970, Zillich & Dowson 1973, Scarfe *et al.* 1995, Omer *et al.* 2004), but they could not do so predictably after filling. Clark & ElDeeb (1993) reported that filled lateral and accessory canals on cleared teeth, did not always appear on radiographic images.

Linear dye leakage was less than the apical dye leakage for AH Plus, Endométhasone, Sealapex and Pulp Canals Sealer (EWT) (Siqueira *et al.* 1995, Lucena-Martin *et al.* 2002, Schäfer & Olthoff 2002, Camps & Pashley 2003). The smaller diameter of the lateral canals when compared with the apical foramen could

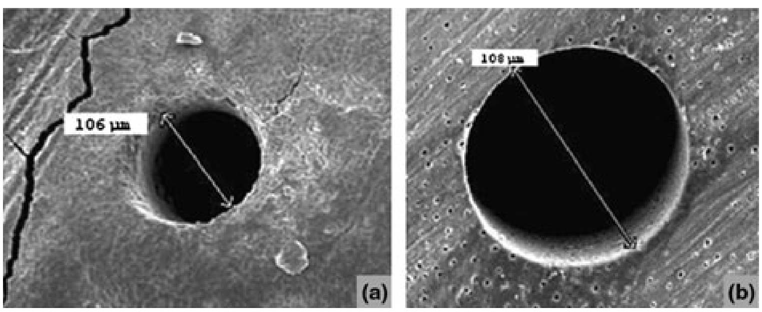

Figure 6 SEM images of lateral canal orifices demonstrating the regularity of 0.1 mm drill perforations, (a) outside surface of dental root (106 µm 140× magnification), (b) inside surface of dental root (108 µm 330× magnification) note the relationship of the artificial lateral canal and the dentinal tubules diameters.

provide better conditions for the sealer to improve their capacity to resist leakage.

The new resin filling system (Epiphany/Resilon) resulted in less leakage through artificial lateral canals only when it was compared with Pulp Canal Sealer (EWT). When this system was tested, significantly less microbial leakage was obtained than with all other groups in which AH 26 was used as a sealer (Shipper *et al.* 2004). Epiphany and Resilon also presented less dye leakage than Tubli-Seal and gutta-percha during apical leakage test (Aptekar & Ginnan 2006). It may be that Epiphany did not demonstrate better results in the present work because the primer did not efficiently reach the dentine inside the lateral root canal, compromising the bond between resin and dentine.

Although a complete apical seal cannot be achieved either with Resilon/Epiphany or sealer and gutta-percha (Tay *et al.* 2005), the physical presence of the sealer and its antimicrobial property might eliminate or inhibit the growth of microorganisms in the root canal system (Siqueira *et al.* 2000, Saleh *et al.* 2004).

Conclusions

Endométhasone did not comply with either ADA 57 or ISO 6876 specifications and Sealapex did not comply with ISO 6876. Lateral canal filling by sealers were not statistically significantly different for the five sealers tested. Dye leakage demonstrated that AH Plus, Epiphany and Sealapex permitted less leakage than Pulp Canal Sealer (EWT) ($P < 0.05$). Radiographs were not able to show lateral canal filling in approximately 8% of cases. There is no correlation between the flow required by the ADA 57 and ISO 6876 specifications and the sealer's ability to fill 0.1 mm artificial lateral canals.

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References

Altman M, Guttuso J, Seidberg BH, Langeland K (1970) Apical root canal anatomy of human maxillary central incisors. *Oral Surgery, Oral Medicine and Oral Pathology* **30**, 694–9.

American National Standards/American Dental Association (1983) *Specification No. 57 for Endodontic Filling Materials*. Chicago, IL, USA: American National Standards/American Dental Association.

Aptekar A, Ginnan K (2006) Comparative analysis of microleakage and seal for 2 obturation materials: Resilon/Epiphany and gutta-percha. *Journal of the Canadian Dental Association* **72**, 245.

Barkhordar RN, Stewart GG (1990) The potential of periodontal pocket formation associated with untreated accessory canals. *Oral Surgery, Oral Medicine and Oral Pathology* **70**, 769–72.

Camps J, Pashley D (2003) Reliability of the dye penetration studies. *Journal of Endodontics* **29**, 592–4.

Clark DS, ElDeeb ME (1993) Apical sealing ability of metal versus plastic carrier Thermafil obturators. *Journal of Endodontics* **19**, 4–9.

Daronch M, Rueggeberg FA, De Goes MF (2005) Monomer conversion of pre-heated composite. *Journal of Dental Research* **84**, 663–7.

De Deus QD (1975) Frequency, location, and direction of the lateral, secondary, and accessory canals. *Journal of Endodontics* **1**, 361–6.

Dulac KA, Nielsen CJ, Tomazic TJ, Ferrillo PJ Hatton JF Jr (1999) Comparison of the obturation of lateral canals by six techniques. *Journal of Endodontics* **25**, 376–80.

Goldberg F, Artaza LP, De Silvio A (2001). Effectiveness of different obturation techniques in the filling of simulated lateral canals. *Journal of Endodontics* **27**, 362–4.

Goldberg F, Artaza LP, De Silvio AC (2002) Influence of calcium hydroxide dressing on the obturation of simulated lateral canals. *J Endod* **28**, 99–101.

Grossman LI (1976) Physical properties of root canal cements. *Journal of Endodontics* **2**, 166–75.

Grossman LI (1982) The effect of pH of rosin on setting time of root canal cements. *Journal of Endodontics* **8**, 326–7.

Himel VT, Cain CW (1993) An evaluation of the number of condenser insertions needed with warm lateral condensation of gutta-percha. *Journal of Endodontics* **19**, 79–82.

International Organization for Standardization (2001) *ISO-6876 Dental Root Canal Sealing Materials*. Geneva, Switzerland: International Organization for Standardization.

Karagoz-Kucukay I (1994) Root canal ramifications in mandibular incisors and efficacy of low-temperature injection thermoplasticized gutta-percha filling. *Journal of Endodontics* **20**, 236–40.

Kirkham DB (1975) The location and incidence of accessory pulpal canals in periodontal pockets. *Journal of American Dental Association* **91**, 353–6.

Lucena-Martin C, Ferrer-Luque CM, Gonzalez-Rodriguez MP, Robles-Gijon V, Navajas-Rodriguez de Mondelo JM (2002) A comparative study of apical leakage of Endométhasone, Top Seal, and Roeko Seal sealer cements. *Journal of Endodontics* **28**, 423–6.

Madison S, Wilcox LR (1988) An evaluation of coronal microleakage in endodontically treated teeth. Part III. In vivo study. *Journal of Endodontics* **14**, 455–8.

Moraes FG, Bramante CM, Moraes IG, Carneiro E, Menezes R (2004) Influence of the EDTA, ND:YAG Laser and association of both on the filling of artificial lateral root canals. *Journal of Applied Oral Science* **12**, 22–6.

Oliveira DP, Barbizam JV, Trope M, Teixeira FB (2006) Comparison between gutta-percha and resilon removal using two different techniques in endodontic retreatment. *Journal of Endodontics* **32**, 362–4.

Omer OE, Al Shalabi RM, Jennings M, Glennon J, Claffey NM (2004) A comparison between clearing and radiographic techniques in the study of the root-canal anatomy of maxillary first and second molars. *International Endodontic Journal* **37**, 291–6.

Pecora JD, Ribeiro RG, Guerisoli DM, Barbizam JV, Marchesan MA (2002) Influence of the spatulation of two zinc oxide-eugenol-based sealers on the obturation of lateral canals. *Pesquisa Odontologica Brasileira* **16**, 127–30.

Reader CM, Himel VT, Germain LP, Hoen MM (1993) Effect of three obturation techniques on the filling of lateral canals and the main canal. *Journal of Endodontics* **19**, 404–8.

Saleh IM, Ruyter IE, Haapasalo M, Orstavik D (2004) Survival of Enterococcus faecalis in infected dentinal tubules after root canal filling with different root canal sealers in vitro. *Int Endod J* **37**, 193–8.

Scarfe WC, Fana CR Farman AG Jr (1995) Radiographic detection of accessory/lateral canals: use of RadioVisioGraphy and Hypaque. *Journal of Endodontics* **21**, 185–90.

Schäffer E, Olthoff G (2002) Effect of three different sealers on the sealing ability of both thermafil obturation and cold laterally compacted gutta-percha. *Journal of Endodontics* **28**, 638–42.

Shipper G, Orstavik D, Teixeira FB, Trope M (2004) An evaluation of microbial leakage in roots filled with a thermoplastic synthetic polymer-based root canal filling material (Resilon). *J Endod* **30**, 342–7.

Silver GK, Love RM, Purton DG (1999) Comparison of two vertical condensation obturation techniques: Touch 'n Heat modified and System B. *International Endodontic Journal* **32**, 287–95.

Siqueira FJ, Fraga RC Jr, Garcia PF (1995) Evaluation of sealing ability, pH and flow rate of three calcium hydroxide-based sealers. *Endodontics and Dental Traumatology* **11**, 225–8.

Siqueira JF Rocas Jr IN, Favieri A, Abad EC, Castro AJ, Gahyva SM (2000) Bacterial leakage in coronally unsealed root canals obturated with 3 different techniques. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **90**, 647–50.

Tay FR, Loushine RJ, Weller RN et al. (2005) Ultrastructural evaluation of the apical seal in roots filled with a polycaprolactone-based root canal filling material. *Journal of Endodontics* **31**, 514–9.

Venturi M, Prati C, Capelli G, Falconi M, Breschi L (2003) A preliminary analysis of the morphology of lateral canals after root canal filling using a tooth-clearing technique. *International Endodontic Journal* **36**, 54–63.

Weine FS (1984) The enigma of the lateral canal. *Dental Clinics of North America* **28**, 833–52.

Weis MV, Parashos P, Messer HH (2004) Effect of obturation technique on sealer cement thickness and dentinal tubule penetration. *International Endodontic Journal* **37**, 653–63.

Weisman MI (1970) A study of the flow rate of ten root canal sealers. *Oral Surgery, Oral Medicine, Oral Pathology* **29**, 255–61.

Wu MK, Wesselink PR (1993) Endodontic leakage studies reconsidered. Part I. Methodology, application and relevance. *International Endodontic Journal* **26**, 37–43.

Zaia AA, Nakagawa R, De Quadros I et al. (2002) An in vitro evaluation of four materials as barriers to coronal microleakage in root-filled teeth. *International Endodontic Journal* **35**, 729–34.

Zillich R, Dowson J (1973) Root canal morphology of mandibular first and second premolars. *Oral Surgery, Oral Medicine and Oral Pathology* **36**, 738–44.