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Sealing properties of two contemporary single-cone obturation systems

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Abstract

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Aim To compare the sealing of root canals filled with two single-cone obturation systems and a warm vertical compaction technique.

Methodology Forty-two single-rooted teeth were decoronated to obtain 17-mm-long root segments. The root canals were cleaned and shaped to size 40, 0.06 taper and filled with: (i) warm vertical compaction with AH Plus (control); (ii) ActiV GP and (iii) GuttaFlow with single master cones. Leakage was evaluated by fluid filtration at 10 psi before root resection, and after 3, 6, 9 and 12 mm apical resections. Repeated measures ANOVAS on ranks and Dunn's multiple comparison tests were performed to examine differences in fluid flow rates amongst different resection lengths for each filling technique. The surface and interior aspects of glass–ionomer filler-coated ActiV GP gutta-percha cones was evaluated with SEM.

Results No statistical difference amongst the filling techniques was seen at 0 and 3 mm root resections. ActiV GP and GuttaFlow exhibited more leakage than AH Plus at 6, 9 and 12 mm resections. AH Plus recorded the best overall results. A nonhomogeneous coating of glass–ionomer fillers on the surface of ActiV GP cones was detected.

Conclusions The two single-cone techniques examined are as effective in sealing the apex as AH Plus when the latter was used with warm vertical compaction. It is further hypothesized that the inferior coronal seal of these single-cone techniques may be improved with the placement of accessory cones to reduce sealer thickness or an immediate coronal adhesive restoration.

Keywords: ActiV GP, AH Plus, Flodec, fluid filtration, GuttaFlow, single-cone.

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Introduction

Although treatment outcomes of contemporary root canal treatment are favourable, filling of the root canal may not result in a long-term optimal seal (Shipper *et al.* 2004). Many studies have indicated that leakage, whether apical or coronal, adversely affects the outcome of root canal treatment (Ray & Trope 1995, Hommez *et al.* 2002).

The role of chemomechanical debridement in the disinfection of the root canal is well established (Coldero *et al.* 2002). Following cleaning and shaping, a filling material should provide a suitable seal of the canal space to prevent further ingress of tissue fluids, bacteria and their by-products (Tang *et al.* 2002, Williamson *et al.* 2005). It is generally accepted that conventional gutta-percha and endodontic sealers do not provide a fluid-tight seal (Friedman *et al.* 1997, De Moor & Hommez 2002). Leakage through a filled root canal may take place along the sealer-dentine and sealer-root

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filling material interfaces or through voids within the sealer. Hence, the quality of a root filling is highly dependent upon the sealer distribution and its adherence to the dentinal walls and gutta-percha (Pommel *et al.* 2003). Single-cone techniques performed with conventional sealers have been perceived to be less effective in sealing root canals than the warm gutta-percha vertical compaction technique (Beatty *et al.* 1986, Kardon *et al.* 2003). However, noncompaction, single-cone filling of root canals has recently been revived (ElAyouti *et al.* 2005, Zmener *et al.* 2005) with the introduction of greater taper master cones that closely match the geometry of nickel-titanium instrumentation systems (Gordon *et al.* 2005). The advent of contemporary root canal sealing systems that claim to create bonds along the sealer-gutta-percha interface via modifications of the sealer or the root filling material (Hiraishi *et al.* 2005, Tay *et al.* 2005a,b) may also support the use of a single-cone obturation technique.

Fluid filtration is a well-accepted method for evaluating leakage in root canals (Derkson *et al.* 1986, Wu *et al.* 1994). This technique was found to be more effective than linear dye penetration in assessing the amount of fluid traversing through a filled canal (Çobankara *et al.* 2002). The recent adaptation of a computerized fluid filtration device for dentine permeability testing (Camps *et al.* 2002, Hashimoto *et al.* 2004) to examine fluid flow across filled root canals was found to increase the sensitivity and accuracy of the technique (Orucoglu *et al.* 2005).

The aim of this study was to compare the sealing ability of two single-cone, noncompaction techniques with the gutta-percha warm vertical compaction technique using a fluid filtration protocol. The null hypothesis tested was that there are no differences in the seal along different parts of a root canal obturated with the three obturation techniques.

Material and methods

Forty-two extracted human single-rooted anterior teeth, stored in 0.9% sodium chloride containing 0.02% sodium azide solution at 4 °C for preventing bacterial growth were used in this study. The teeth were decoronated using a low speed diamond saw (Buehler; Isomet, Lake Bluff, NY, USA) to create root segments that were approximately 17 mm long. Bucco-lingual and mesio-distal radiographs were taken for evaluating the root canal morphology (ProVision Dental Systems, Inc., Redwood City, CA, USA), with the canals classified as having being round or oval-shaped. The rationale for this evaluation was to endure that both round and oval-shaped canals were equally represented and distributed amongst all the experimental groups. Cleaning and shaping and canal filling were performed under an operating microscope (Global Surgical Corp., St Louis, MO, USA). Canal patency was achieved with a size 15 Flex-o-file (Dentsply Maillefer, Ballaigues, Switzerland). Working lengths were established 0.5 mm short of the apical foramen. Instrumentation was performed with a crown-down technique using EndoSequence 0.06 taper nickel-titanium rotary instruments (Brasseler USA, Savannah, GA, USA) to a size 40. The root canals were alternately rinsed with 5 mL of 17% ethylenediamine tetraacetic acid and 5 mL of 6.15% sodium hypochlorite in between instrumentation, with the former employed as the final rinse (additional 10 mL). A size 40, 0.06 taper master gutta-percha cone was trimmed to achieve tug-back, with the nature of gutta-percha cone dependent upon the group designation. Each canal was dried with multiple paper points. The roots were equally divided into three experimental groups ($n = 12$) and two control groups ($n = 3$). Each experimental group contained 25% round canals and 75% oval-shaped canals.

Group I. Warm vertical condensation of gutta-percha/AH Plus sealer

Each canal was fitted with an EndoSequence size 40, 0.06 taper gutta-percha master cone (Brasseler) that was used to apply an epoxy resin-based sealer (AH Plus; Dentsply Caulk, Milford, DE, USA) to the canal walls by rotating it counterclockwise (Wu *et al.* 2001). The gutta-percha was down-packed with a System B heat source (SybronEndo, Orange, CA, USA) placed 4 mm from the working length and backfilled with low melting point gutta-percha pellets (Flow 150; Spartan, Fenton, MO, USA) using an Obtura II (Spartan). Upon obturation and compaction, the last 2 mm of gutta-percha was removed from the canal orifice, followed by the placement of a provisional restoration (Cavit; 3M ESPE, Seefeld, Germany).

Group II. ActiV GP Precision Obturation System (Brasseler USA)

Each canal was fitted with a single size 40 ActiV GP 0.06 taper gutta-percha master cone that corresponded with the dimension of the largest EndoSequence nickel-titanium rotary instrument taken to working length. The ActiV GP gutta-percha is a glass–ionomer filler containing gutta-percha cone that is also coated with a layer of glass–ionomer fillers along the cone surface. By doing so, a stiffer gutta-percha cone is achieved that transforms it into a gutta-percha core/cone, enabling the latter to be functioned as both the tapered filling cone and as its own carrier core, thus avoiding the need for a separate interior carrier of plastic or metal (Koch & Brave 2006). The presence of the glass–ionomer filler-coated gutta-percha cone also allows it to be bonded to the root dentine via a glass–ionomer sealer (Koch *et al.* 1994), creating a claimed, 'single-cone monoblock obturation'. The master cone was coated with the ActiV GP sealer following the manufacturer's instructions and slowly inserted into the canal to its working length, allowing the excess sealer to extrude coronally adjacent to the gutta-percha cone. After setting of the sealer, the master cone was seared off at 2 mm beneath the canal orifice. A layer of ActiV GP sealer was placed on top of the master cone to create a coronal seal, as recommended by the manufacturer.

Group III. GuttaFlow (Colténe-Whaledent, Altstätten, Switzerland)

Each canal was fitted with an EndoSequence size 40, 0.06 taper gutta-percha master cone (Brasseler). The polydimethylsiloxane-based GuttaFlow sealer is the successor product of RoekoSeal (Colténe-Whaledent, Langenau, Germany) that contains fine gutta-percha powder and nano-silver in addition to the polydimethylsiloxane, zinc oxide, zirconium dioxide, paraffin-based oil, hexachloroplatinic acid and silicic acid that are present in the original RoekoSeal. The GuttaFlow capsule was titurated for 30 s and the sealer was inserted into the root canal using the dispenser and 'Canal Tip' provided by the manufacturer. The gutta-percha master cone was also coated with the sealer, according to the manufacturer's instructions, and slowly inserted into the canal. In the event that an oval-shaped canal was encountered, the 'Canal Tip' was re-inserted to dispense additional sealer to the spaces between the master cone and canal walls. This additional backfill with the GuttaFlow sealer was performed according to the manufacturer's instructions. The last 2 mm of gutta-percha was removed from the canal orifice with a System B heat source, followed by the placement of a provisional restoration (Cavit; 3M ESPE).

Positive and negative controls

Three root segments that were filled each with a single size 40, 0.06 taper master gutta-percha cone in the absence of a sealer were used as positive controls to test the maximum fluid flow of the fluid filtration system through the root canals. Three filled root segments were used as negative controls. They were filled as in group I and dipped in molten sticky wax and further covered with nail varnish. Radiographic documentation of the quality of the root filling procedures was performed using the Dexis digital X-ray system (Global Surgical Corp.).

Leakage evaluation

The filled root segments were stored for 7 days at 37 °C and 100% relative humidity. Leakage of the filled roots in each group was evaluated using a modified fluid filtration study design that represents a modification of the previously reported protocol by Pashley & Depew (1986). A Plexiglas connection platform was first constructed by inserting a short length of an 18-gauge stainless steel tubing into a centre hole created in a $2 \times 2 \times 0.6$ cm piece of Plexiglas. The tubing protruded 1 mm from the top of the Plexiglas. A 2 mm deep cavity was then created from the coronal end of each root segment by removing the provisional restoration with a slow speed tungsten carbide bur. This modified technique created a reservoir for the insertion of the protruded metal tubing. The rationale for this modified protocol is that this technique eliminated clogging of the metal tubing and prevented the generation of false-negative results. The tooth segment was attached to the Plexiglas platform and sealed with a cyanoacrylate adhesive (Zapit; Dental Ventures of America, Inc., Anaheim Hills, CA, USA). Each filled root was cemented with Zapit to the Plexiglas platform so that the coronal root canal orifice was directly above the orifice of the metal tubing.

Each Plexiglas-root assembly was attached via polyethylene tubing (Fisher Scientific, Pittsburg, PA, USA) to a computerized fluid filtration device (Flodec; De Marco Engineering, Geneva, Switzerland). The latter, in turn, was connected to a water reservoir inside a modified pressure cooker. Nitrogen gas was employed for delivering a pressure of 10 psi to force the water apically through any voids within the root filling. Quantification of the fluid flow ($\mu L\ min^{-1}$) was performed by monitoring the displacement of a water bubble introduced into a glass capillary tube in the Flodec device. Fluid flow measurement was assisted by the emission of an infrared light through the edge of the bubble to a light-sensitive photodiode. Computerized automated collection was performed every 1.04 s using

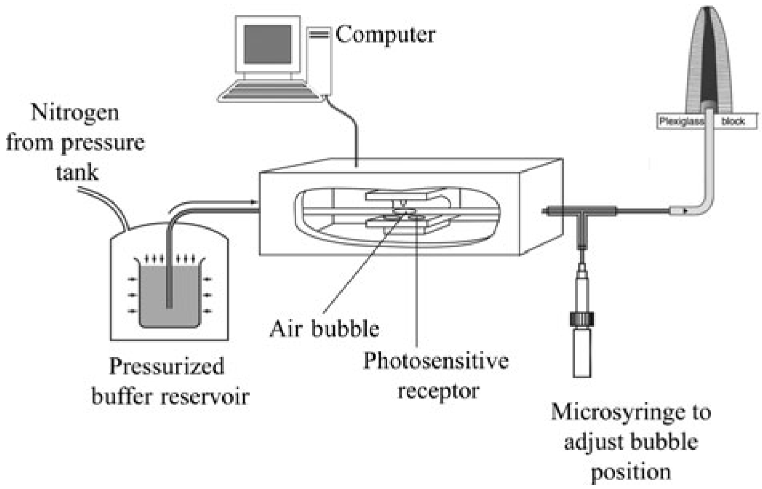


Figure 1 A schematic of the system used to measure fluid flow along the filled root canals.

the Flodec software (Fig. 1). Because the change in fluid flow with time could be monitored using the graphic display, the sensitivity of the technique was increased by allowing the system to run until the fluid flow became stable prior to recording.

After fluid filtration through the entire root canal was recorded, each specimen was removed from the fluid filtration device and the apical part of the root segment was sectioned at 3 mm intervals with the Isomet saw under copious water irrigation (Wu *et al.* 2003, Gillespie *et al.* 2006). Fluid filtration was re-measured at each interval until 12 mm of the root was removed (i.e. four resections). The mean fluid flow was compiled for each resection length. Resections were not performed for the positive and negative controls.

To account for the intrinsic permeability of the polyethylene tubing connections within the fluid filtration system, multiple fluid flow measurements (10 min each) were repeated with the exit connection clamped with a haemostat. The intrinsic permeability of the testing system, expressed also in μL min^{-1}, was subtracted from the mean fluid flow for each resection length of the respective root filling technique to generate the mean 'adjusted' fluid flow. Moreover, the same set of connections was used with the same Plexiglas platform to ensure that the system permeability was unchanged throughout the experiment. After performing the measurements with one specimen, the remaining sectioned root stub was removed and a new-filled root canal was attached to the same Plexiglas platform.

For the positive control group, the extremely rapid fluid movement did not permit the recording of linear fluid movement by the Flodec device. Accordingly, the latter was removed from the fluid filtration setup. A pre-weighed beaker was placed over the apex of the root segment to collect the water that was expressed through the apex for 1 min at 10 psi pressure. The weight of the water that was collected was converted into volume, from which the fluid flow in μL min^{-1} was deduced.

Statistical analysis

The mean 'adjusted' fluid flow, generated at 10 psi (i.e. 703 cm of water pressure), was normalized and expressed as the hydraulic conductance (μL min^{-1} cmH_2O^{-1}). Because the pooled data from the 15 subgroups (five resection lengths for each of the three filling techniques) were not normally distributed, individual repeated measures ANOVA on ranks and Dunn's multiple comparison test were first performed to examine the consistency of each filling technique at different resection lengths. Kruskal–Wallis ANOVAs and Dunn's multiple comparison tests were subsequently conducted to examine the sealing efficacy of the three filling techniques at each resection length. All statistical significance was set at $\alpha = 0.05$.

Silver tracer filtration

After the final root resection, silver tracer filtration was performed with shielding from direct light to examine the coronal leakage from the remaining sectioned root stump of the specimens. To avoid contamination of the Flodec device, the silver filtration procedure was conducted by direct connection of the Plexiglas platform to the pressurized 50 wt% ammoniacal silver nitrate-containing reservoir at 10 psi via a new polyethylene tubing. The rationale for using ammoniacal silver nitrate (pH 9.5) was to prevent inadvertent demineralization of the intraradicular dentine or glass–ionomer sealer with the use of an acidic, conventional silver nitrate solution (Tay *et al.* 2002). After 15 min, the silver nitrate that penetrated the gaps within the root fillings was reduced to metallic silver by immersing in photodeveloping solution for 24 h. The extent of silver penetration was recorded by digital photography at 2× magnification.

Scanning electron microscopy (SEM)

Because the glass–ionomer filler containing gutta-percha cones employed in ActiV GP were different from conventional gutta-percha cones, SEM was employed to examine the morphology of the surface and the internal aspects of these novel gutta-percha cones. Five size 40, 0.06 taper ActiV GP cones were used for the examination of the variability of the filler-coated surfaces. Five additional ActiV GP cones were cryofractured under liquid nitrogen at lengths between D3 and D5. The same procedures were repeated with the same dimension EndoSequence cones that were used in the other two filling techniques. The cones were mounted on aluminium stubs, coated with gold/palladium and examined with a SEM (XL-30 FEG; Philips, Eindhoven, The Netherlands) operating at 10 keV.

Results

Representative examples of the fluid flow measurements for each experimental group at different resection lengths are shown in Fig. 2(a–c). The intrinsic permeability of the fluid filtration system (0.029 ± 0.04 μL min^{-1} cmH$_2$O^{-1}) is shown in Fig. 2d, which was not different from the nonadjusted mean fluid flow rate of the negative control group (0.033 ± 0.012 μL min^{-1} cmH$_2$O^{-1}).

The hydraulic conductance values for the 15 subgroups, after adjustment for the intrinsic permeability of the fluid filtration system, are represented graphically in Fig. 3. Significant differences in hydraulic conductance were observed amongst the different resection lengths for

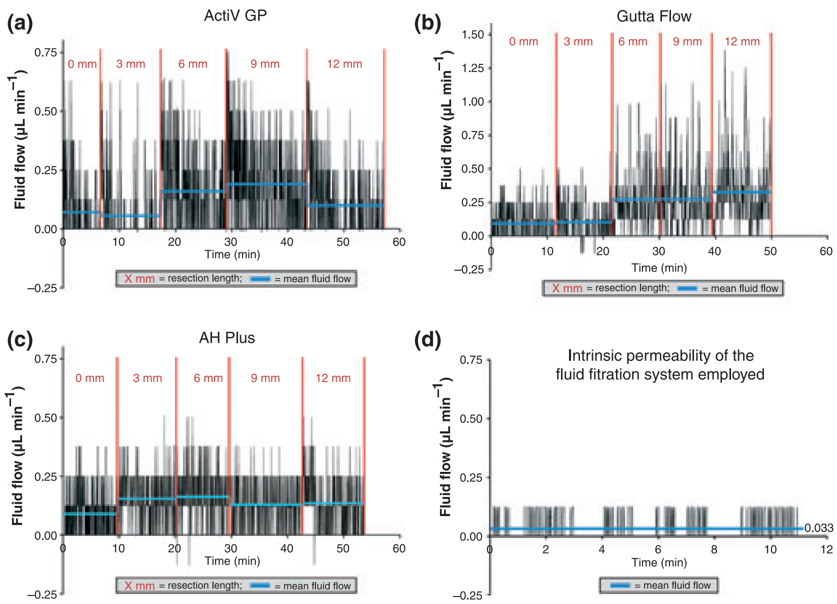


Figure 2 (a) A representative example of the fluid filtration measurements through an ActiV GP-obturated root canal at different resection lengths. The vertical black lines represent the fluid flow recorded every 1.04 s by the Flodec device at 10 psi pressure. The mean fluid flow for each resection length (represented as horizontal blue lines) represents the actual data recorded prior to adjustment for the intrinsic permeability of the fluid filtration system. (b) A representative example of the fluid filtration measurements through a GuttaFlow-obturated root canal at different resection lengths. (c) A representative example of the fluid filtration measurements through an AH Plus-obturated root canal (control warm vertical compaction group) at different resection lengths. (d) The mean fluid flow obtained at 10 psi with the exit polyethylene tubing clamped represents the intrinsic permeability of the fluid filtration system. This mean value was subsequently subtracted from the mean fluid flow obtained for all root resection lengths to yield the 'adjusted' mean fluid flow for each resection length.

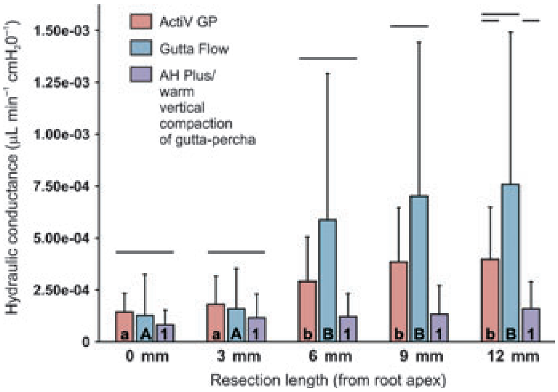


Figure 3 Comparison of the hydraulic conductance of the three root filling groups. Within each root filling group, resection lengths with the same characters/numerals (lower case letters for ActiV GP, upper case letters for GuttaFlow and numerals for AH Plus/warm vertical compaction) are not statistically significant ($P > 0.05$). For each resection length, horizontal bars above the respective root filling groups indicate no statistical difference in hydraulic conductance ($P > 0.05$).

ActiV GP ($P = 0.024$; Power = 0.92) and GuttaFlow ($P < 0.001$; Power = 0.95) but not for AH Plus/gutta-percha warm vertical compaction ($P = 0.140$; Power = 0.60). For ActiV GP and GuttaFlow, the hydraulic conductance of the intact filled roots and resections at 3 mm were similar and were significantly lower than those values obtained at 6, 9 and 12 mm resections, which in turn, were not significantly different from one another. For comparison, the hydraulic conductance of the positive control group was 75.03 ± 6.57 μL min^{-1} cmH_2O^{-1}, the mean of which was 633 990 times the mean hydraulic conductance of the pooled data derived from intact canals of the three root filling groups.

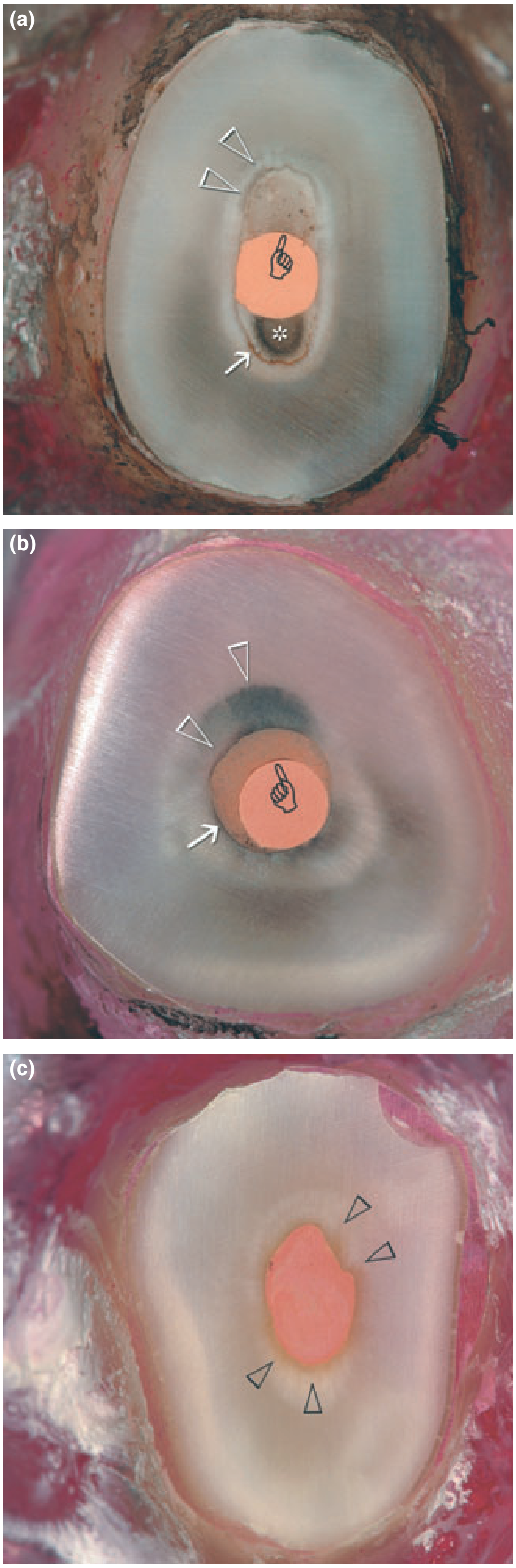
The three root filling techniques sealed equally well before sectioning ($P = 0.209$), and after 3 mm ($P = 0.259$) and 6 mm resections ($P = 0.081$) (Fig. 3). At 9 mm resection, leakage in ActiV GP and GuttaFlow were significantly higher ($P = 0.018$) than warm vertical compaction of gutta-percha using AH Plus sealer, but were not significantly different from one another. Significant difference amongst the three root filling techniques was observed at 12 mm resection ($P = 0.025$), with the hydraulic conductance of GuttaFlow being statistically similar to that of ActiV GP, and the latter being statistically similar to that of the warm vertical compaction technique examined.

When leakage of the sectioned roots at 12 mm resections were examined using silver tracer, hydrated specimens from the ActiV GP group revealed brown to black silver deposits within the sealer, and partial silver staining of the sealer-gutta-percha and sealer-dentine interfaces (Fig. 4a). Mild silver penetration into the dentinal tubules was also observed. Similar features were also observed for GuttaFlow, with more extensive silver penetration into the dentinal tubules (Fig. 4b). Leakage in the AH Plus group was also observed, albeit to a milder extent, as manifested by the light brown silver deposits within the dentinal tubules (Mair 1992) (Fig. 4c).

The SEM examination of the glass–ionomer filler-coated ActiV GP cones revealed a highly variable extent in which the cone surfaces were covered with filler particles. In some cones, filler clusters were sparsely observed, exposing irregular, dimpled surfaces that were either devoid of fillers or in which the fillers were dislodged (Fig. 5a). In other cones, a dense aggregation of filler particles was identified at similar locations from the cone tip (Fig. 5b). This filler layer was approximately 2 μm thick when the cryofractured cones were examined (Fig. 5c). In addition, large filler particles >5 μm in diameter, probably representing glass–ionomer fillers, were present within the interior of the cryofractured ActiV GP gutta-percha cones (Fig. 5d). These fillers were absent from the surface and the cone interior of the EndoSequence gutta-percha cones (not shown).

Discussion

From the fluid filtration data presented in Fig. 1, it can be appreciated that the computerized Flodec device is a highly sensitive method of measuring fluid flow along a glass capillary tube. Indeed, the Flodec device is so sensitive that the intrinsic permeability of the fluid filtration system had to be subtracted from the actual measurements to account for the minute positive fluid flows observed in the negative control specimens. As no differences were observed in the hydraulic conductance of the three root filling techniques at the apical 0–3 mm (Fig. 3) even with the use of such a sensitive detection method, one may reasonably conclude that the two single-cone obturation systems created apical seals that are comparable with that of a warm vertical compaction technique using gutta-percha and an epoxy resin-based sealer. However, as the hydraulic conductance of the two contemporary single-cone systems are higher and more variable than the warm vertical compaction technique at the coronal 9–12 mm, one has to reject the null hypothesis that there are no differences in the seal along different parts



of a root canal obturated with the three obturation techniques.

Because of limitations in the depth of penetration of the heat carrier in a warm vertical compaction technique (Yared & Bou Dagher 1995, Venturi *et al.* 2002, Wu *et al.* 2002a, Venturi & Breschi 2004, Diemer *et al.* 2006), filling of the apical 3–5 mm of an instrumented root canal with warm vertical compaction may, at best, be viewed upon as a variation of a single cone technique. With the use of rotary nickel titanium instruments, such a concept is fortified by the availability of master cones that closely match the taper of the rotary instruments (Gordon *et al.* 2005). From this perspective, the two contemporary single-cone techniques that consist of matching a cone to the prepared canal may be advantageous in locations such as the mesio-buccal canals of maxillary and mesial canals of mandibular molars where the size of the master gutta-percha cone and the shape of the canal preparation are closely matched.

A well-accepted disadvantage of single-cone techniques is the inferior adaptation of a single master cone to the middle and coronal thirds of an irregular-shaped canal (Wesselink 2005), in which increases in sealer distribution (Wu *et al.* 2000) with significantly more dye and fluid leakage (Beatty 1987) have been reported. Oval-shaped root canals were included in the study to simulate the variability of the clinical conditions and the effectiveness of the filling techniques (Wu *et al.* 2003). The fluid filtration results of the present study supported these findings in that the incorporation of innovative technologies in the two contemporary single cone systems does not result in improvement of the seal along the coronal third of the root fillings in the event

Figure 4 Examples of silver leakage exhibited by the three root filling groups at 12 mm resection lengths. (a) An ActiV GP specimen with leakage observed partially along the ActiV sealer-root dentine interface (arrow) and partially along the sealer-glass–ionomer filler-coated gutta-percha interface (pointer). Some silver penetration could be identified within the dentinal tubules (open arrowheads). In addition, silver nitrate penetration into the sealer could be seen in the form of black to brown silver deposits (asterisk). (b) A GuttaFlow specimen with partial silver staining along the GuttaFlow-root dentine interface (arrow) and the GuttaFlow-gutta-percha interface (pointer). Some silver penetration was also observed within the dentinal tubules (open arrowheads). (c) An AH Plus/gutta-percha warm vertical compaction specimen in which silver penetration could be seen within the dentinal tubules (open arrowheads).

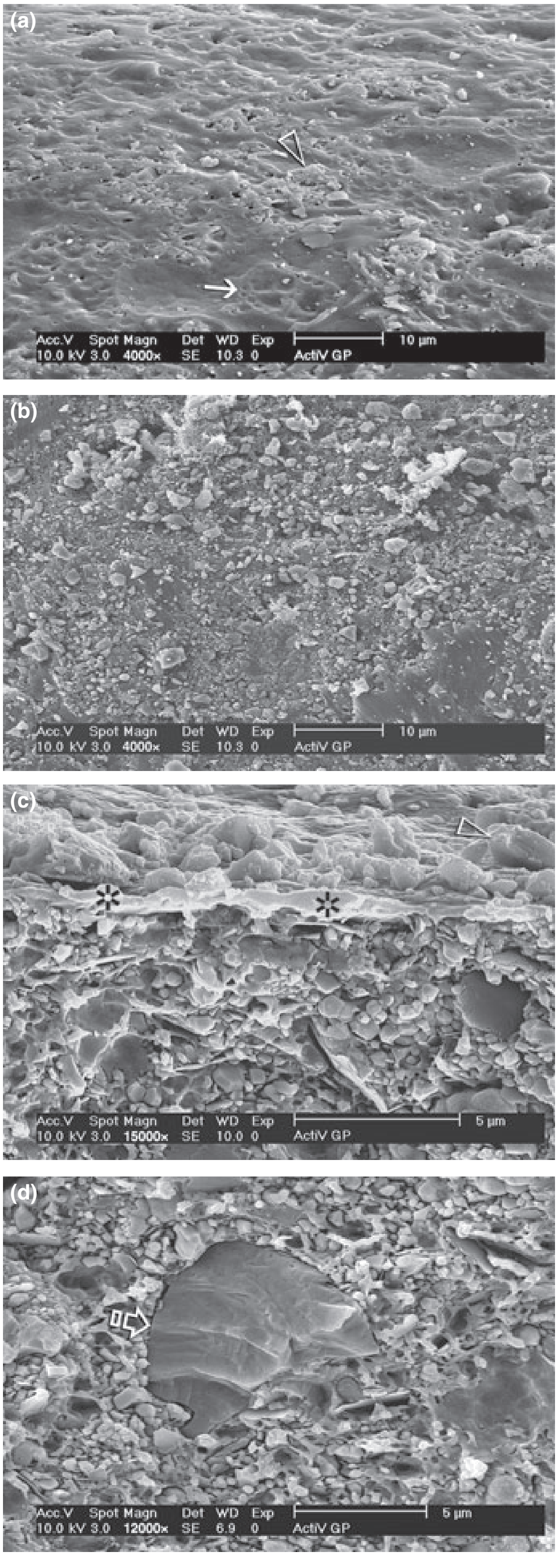


Figure 5 Scanning electron micrographs of the morphological characteristics of the glass–ionomer filler containing ActiV GP gutta-percha cones taken at 3–4 mm from the cone tips. (a) An example of a cone surface with sparsely distributed glass–ionomer filler clusters (open arrowhead). Many of the glass–ionomer fillers have dislodged, leaving a rough, dimpled surface (arrow) that was devoid of filler particles. (b) An example of an ActiV GP cone surface with more densely distributed glass–ionomer filler particles. (c) A cyrofractured section of an ActiV GP gutta-percha cone showing the demarcation (asterisks) between the cone surface and the highly filled cone interior. An approximately 2 μm thick layer of glass–ionomer filler particles (open arrowhead) could be identified along the cone surface. (d) A cyrofractured section of the highly filled cone interior of an ActiV GP gutta-percha cone. Large glass–ionomer filler particles (arrow) could also be identified within the gutta-percha.

that a thick sealer layer is present, such as in the case of an oval-shaped canal (Fig. 4a,b). Thus, reduction of sealer volume or thickness, either through passive insertion or lateral compaction of accessory cones, may improve the coronal seal of the single-cone obturation systems examined. This additional step, however, may not be absolutely required whether the root canal is subsequently restored with polyethylene fibre or glass fibre dowel systems, both of which have been shown to reduce the coronal leakage of root-filled teeth (Shipper & Trope 2004, Usumez *et al.* 2004).

For GuttaFlow, the manufacturer claims that the sealer expands 0.2% on setting. This expansion, combined with the close adaptation of the gutta-percha cone against the instrumented canal wall, may enhance sealer flow and adaptation against the dentinal tubule walls in the apical third of the root canal, creating a seal that is comparable with that of warm vertical compaction of gutta-percha and AH Plus sealer. Whilst, it is debatable that sectioning of the filled canal may result in tearing of the material, the same process was applied to canals filled with the three different techniques, with differences in silver leakage results along the coronal third of these canals. Presumably, the lack of adaptation between the gutta-percha master cone and the coronal third of an oval-shaped canal does not permit the generation of a filling pressure that enables the sealer to uniformly penetrate the circumferential dentinal tubules along the coronal third of the root canal. The same may also apply to the subsequent passive filling of the coronal canal spaces via the insertion of the GuttaFlow 'canal tip'. It is noteworthy that the incorporation of gutta-percha particles into the polydimethylsiloxane-based sealer does not appear to create a leak-free seal between the gutta-percha and sealer (Fig. 4b). Presumably, in the absence of heat or a solvent, there is no chemical union between the discrete gutta-filler particles and the gutta-percha master cone. Thus, it is appropriate to see whether a chemical bond between the trans-1,4-polyisoprene component of the gutta-percha master cone and the polydimethylsiloxane component of the sealer may be achieved via the use of a primer coating.

In the case of ActiV GP, a layer of the glass–ionomer sealer placed over the orifice of the filled root canals is recommended by the manufacturer for improving the coronal seal. Although this step has been followed, the glass–ionomer layer was removed prior to the fluid filtration evaluation. The same procedure was also performed for the other two filling techniques by removal of the Cavit provisional restorations. Such a protocol was adopted as the objective of the study was to evaluate the sealing properties of root fillings rather than those created by Cavit or a glass–ionomer restoration. Moreover, the observation of fairly extensive silver penetration within the ActiV GP sealer suggests that like other glass–ionomer sealers, this sealer is susceptible to water sorption and leaching (Carvalho-Junior *et al.* 2003, Schäfer & Zandbiglari 2003, Donnelly *et al.* 2006). Conversely, polydimethylsiloxane-based sealers, such as GuttaFlow exhibited minimal water sorption and solubility (Donnelly *et al.* 2006), which may account for the consistent seal observed in its predecessor, RoekoSeal over an 18-month period (Wu *et al.* 2002b). Thus, the longevity of a coronal seal created by the use of an ActiV GP layer has to be further investigated before such a technique may be recommended.

Glass–ionomers are considered suitable endodontic sealers because of their adhesion to dental hard tissues (Çobankara *et al.* 2002, De Bruyne & De Moor 2004). However, the contribution of this adhesive property to the root canal seal is controversial, as exemplified by the variable results reported in the literature (de Gee *et al.* 1994, Koch *et al.* 1994, Oliver & Abbott 1998, Miletic *et al.* 1999). The inclusion of a surface coating of glass–ionomer fillers on the ActiV GP gutta-percha cones purportedly allows them to be bonded to the glass–ionomer sealer, thereby improving the seal between the root filling material and the sealer. Conceptually, this would create a monoblock between the root filling material and the intraradicular dentine within the root canal. Such an objective was only partially accomplished, as silver leakage could be identified partially along the gutta-percha sealer and sealer-dentine interfaces (Fig. 4a). It is known that traditional self-curing glass–ionomer cements shrink during setting and, similar to resin composites, create destructive shrinkage stresses along adhesive interfaces, albeit to a smaller extent (Feilzer *et al.* 1988, Davidson *et al.* 1991). Such an issue is consequential, in view of the unfavourable cavity geometry for adhesion within long narrow root canals (Tay *et al.* 2005a,b). This prompted the authors to examine the variability of the filler coating along the surface of these gutta-percha cones. These fillers are deposited onto the gutta-percha cone surface using a technology derived from the coating of medical stents, enabling the fillers to be retained during flexing of the gutta-percha cones (K. Koch, personal communication). SEM examination of these cone surfaces revealed that the filler density is nonhomogenous, with dimpled surfaces that were almost completely devoid of filler particles (Fig. 4a).

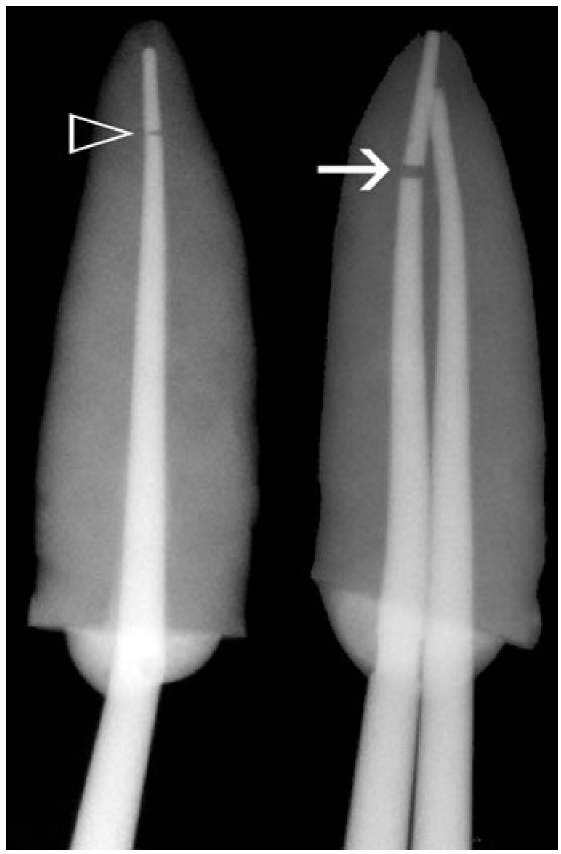


Figure 6 Episodic partial (open arrowhead) and complete (arrow) separation of ActiV GP gutta-percha cones after obturation. These specimens were not included in the present study.

These filler-sparse regions may represent areas where the fillers have been dislodged from the cone surfaces. It is notable that both filler-dense and filler-sparse regions may exist along the same ActiV GP master cone (not shown).

Incorporating a 2 μm thick surface coating of glass–ionomer fillers along the surface of gutta-percha probably increased the stiffness of the master cone, enabling the latter to be used as its own carrier (Koch & Brave 2006). However, the dimension and surface roughness of the cone surface are invariably increased with the presence of this surface filler coating. In the event that tight tug backs are achieved, this may result in partial or complete separation of the master cones (Fig. 6), which necessitates an additional step in retrieving the separated apical cone sections. Whilst this phenomenon was episodic and probably represents a part of the learning curve by the authors in the manipulation of this material, it is prudent that practitioners be duly informed to avoid repeating the authors' experience.

There are limitations in every type of *ex vivo* leakage test (De Bruyne *et al.* 2005). The effect of sectioning and repeated testing of a filled root canal has previously been shown to have minimal effect on the fluid filtration results of some root canal sealing systems (Gillespie *et al.* 2006). The use of 10 psi pressure to evaluate through-and-through voids within root fillings is a taxing method of evaluating leakage in root canals (Camps & Pashley 2003). Although it has been shown that there is no correlation between dye leakage and bacterial leakage in root canals (Barthel *et al.* 1999), the relationship between leakage from fluid filtration and bacterial leakage is unknown. Ideally, both types of leakage should be performed using the same set of specimens. The influence of microbial size (Shipper *et al.* 2004) on bacterial leakage of these contemporary single-cone obturation systems should also be performed in future work.

Conclusions

Within the limits of this study, it may be concluded that the two contemporary single cone obturation systems examined produced apical seals that are comparable with that of warm vertical compaction of gutta-percha using AH Plus sealer. Using a computerized fluid filtration protocol, these two systems exhibited coronal seals that are inferior to those created with the warm vertical compaction technique. Reduction of sealer thickness via lateral compaction of accessory cones to reduce sealer volume appears to be a logical approach for optimizing the coronal seal of these two obturation systems, which has to be confirmed in future studies.

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