Apical and Root Canal Space Sealing Abilities of Resin and Glass Ionomer-Based Root Canal Obturation Systems

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Objective: *To investigate the apical sealing ability of glass ionomer and resin-based root canal obturation systems in comparison to a conventional vertical compaction of warm gutta-percha.*
Methods: *Forty-five extracted human teeth were randomly assigned into 3 groups of 15 each: a resin-based (EndoRez), a glass ionomer-based (Activ GP), and a conventional gutta-percha plus pulp sealer obturation system (GP/EWT). Apical and root canal space sealing abilities were assessed on five cross-sections 1.0 mm apart starting from the apex. Cross-section images were analysed using a focus-variation 3D scanning microscope and unsealed space was calculated as the percentage of total root canal space occupied by voids and debris.*
Results: *EndoRez had significantly higher rate of apical leakage and deeper dye penetration as compared to GP/EWT and Activ GP. EndoRez group had also more voids and debris (22.5%) in the root canal spaces as compared to GP/EWT (10.5%) and Activ GP (10.8%). Apical leakages occurred not only along the root canal walls, but also along the gutta-percha cones with EndoRez as a result of significant polymerisation shrinkage of the resin sealer.*
Conclusion: *Resin-based EndoRez did not form an adequate apical seal of filled root canals. Glass ionomer-based Activ GP was comparable to a vertical compaction of warm gutta-percha plus EWT sealer in sealing root canal spaces.*

Key words: *root canal therapy, gutta-percha, glass ionomer, methacrylate resin, dye leakage*

Adequate sealing of root canal spaces is the most important feature assuring long-term success of root canal treatment. Though root canal obturation with warm gutta-percha and a root canal sealant is considered the gold standard of contemporary endodontics[1], complete sealing of root canal systems is almost impossible with these types of filling materials because they do not adequately adhere to the dentin[2,3]. Dental researchers and clinicians have persistently sought after new materials that allow a uniform and complete sealing of root canal spaces and dentinal tubules. Resin and glass ionomer-based techniques represent such attempts in improving the sealing ability of root canal obturation systems. It is believed that gutta-percha cones impregnated and coated with either glass ionomer or resin will allow a hermetic seal of the root canal spaces when used with corresponding glass ionomer or resin adhesive sealants through the formation of a 'monoblock' of dentin and filling materials[4-6]. Despite unequivocal claims of superiority from respective manufacturers, recent laboratory and clinical studies have not confirmed that these new root canal obturation systems performed better than the conventional ones[7,8].

There is limited information with regard to the sealing ability of glass ionomer or resin-based root canal obturation systems in comparison to vertical compaction of the warm gutta-percha technique. Activ GP™ (Brasseler USA) is marketed as a single-cone obturation technique using a gutta-percha cone impregnated and

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Table 1 Compositions of the root canal sealers used in the present study

Sealants	Composition	Manufacturers
EndoRez™	*Base*: Diurethane Dimethacrylate (DUDMA), Benzoyl Peroxide *Catalyst:* 2,2'-(p-Tolylimino)Diethanol, Triethylene Glycol Dimethacrylate	Ultradent Products
Pulp Canal Sealer™ EWT	*Liquid:* Eugenol *Powder:* Zinc oxide, staybelite resin, bismuth subcarbonate, barium sulfate, sodium borate anhydrate	Kerr Corporation
Activ GP™	*Liquid:* Polycarboxylic acid, tartaric acid *Powder:* Barium aluminosilicate glass powder, dried polyacrylic acid	Brasseler USA

coated with glass ionomer. Bacteria leakage studies comparing the sealing ability of Activ GP with vertical compaction of warm gutta-percha yielded conflicting results[9,10]. The EndoRez™ (Ultradent Products) system includes methacrylate resin-coated gutta-percha cones and a urethane dimethacrylate (UDMA) resin-based sealer. The UDMA sealer is purportedly bondable to both dentin and the gutta-percha resin coating for the establishment of a tight seal[11]. Though some studies demonstrated that the sealing ability of the EndoRez system was superior to that of lateral compaction of gutta-percha[11-13], others have shown that the endodontic seal of the EndoRez system is not as effective as the conventional gutta-percha and sealer systems[2,14-17].

Further studies on the performance of resin and glass ionomer-based root canal obturation systems may provide evidence for clinical practices and help clinicians in their decision making when choosing the glass ionomer or resin-based root canal obturation systems. The purpose of the present study is therefore to investigate the root canal space sealing ability of two glass ionomer and resin-based root canal obturation systems in comparison to the conventional vertical compaction of warm gutta-percha *in vitro*.

Materials and methods

Forty-five extracted human teeth with single straight root canal and mature apices were cleaned, rinsed and sterilised with ethylene oxide for 12 hours. The crowns were removed and each tooth was adjusted to 18 to 20 mm in length. Teeth were randomly assigned into 3 different treatment groups of 15 each. A methacrylate resin-based obturation system (EndoRez), a glass ionomer-based obturation system (Activ GP), and a conventional gutta-percha plus pulp sealer (Kerr EWT, Kerr Corporation) obturation system (GP/EWT) comprised the 3 treatment groups. Compositions of the sealants used in the 3 groups are presented in Table 1.

Root canal preparation and obturation

Root canals were prepared and obturated according to manufacturer recommendations using files and instrumentations suggested in the instruction manuals. All the treatments were performed by the same operator.

In the EndoRez group, an Endo-Eze™ AET handpiece and Endo-Eze AET shaping files were used to prepare the coronal portion of the canal using a milling motion with files sequentially increasing in size. The shaping files were inserted into the canal to the length 3 mm short from the working length. Each file was used until the file was loose in the canal. The apical third was prepared last using Endo-Eze apical files with conventional twist-pull motion. Copious amounts of 5.25% sodium hypochlorite were used to irrigate the canal between each file. Before placing the sealant, canals were dried with paper points and flushed thoroughly with ethylenediaminetetraacetic acid (EDTA). Excess fluid was removed by an Ultradent Capillary tip attached to a high-velocity vacuum system, and canals were dried again with a single paper point. EndoRez Dual Cure Canal Sealer (LOT # B395T) in a TwoSpense®syringe with the Ultra-Mixer™ was mixed and dispensed into the Skini syringe. An Ultradent NaviTip was attached to the Skini syringe and inserted into the canal to 2 to 3 mm of the apex and the sealant was delivered into canal space while slowly withdrawing the NaviTip. EndoRez Points master cone (LOT # B36QX) matching the size of the last apical file used to prepare the apical third was inserted into the canal. Excess EndoRez points were removed with Touch'n Heat™ 5004 (SybronEndo) instrument. The EndoRez sealant was allowed to set before the canal orifice was sealed with a provisional restorative material (Cavit™, 3M ESPE).

In the Activ GP group, the patency of the canal was first established by moving a No. 10 EndoSequence hand file to a depth of approximately one half of the length of the canal. Using the EndoSequence Expeditor™ rotary file, the canal was penetrated until initial engagement was encountered. Using the resistance of the hand file and the progress of the Expeditor file, the appropriate EndoSequence treatment pack size and taper were chosen. The canal was shaped in the crown-down fashion, using successive EndoSequence files from the selected treatment pack. Each file was used for two series of three engagements before moving to the next file (e.g. 50-45-40-35 for large canals). Copious amounts of 5.25% sodium hypochlorite were used to irrigate the canal between each file. The canals were dried with paper points before obturation. The Activ GP Glass Ionomer Sealer liquid (LOT # 1705090) and powder (LOT # 1705145-15B1007) were mixed as instructed and a clean hand file that matched the final size of the preparation was coated with the sealant. The coated hand file was taken to the working length in a circular motion to ensure complete coating of the canal walls. Activ GP gutta-percha cone (LOT # 010807) that matched the last rotary file was coated with the Activ GP Glass Ionomer Sealer and slowly inserted into the working length. The sealant was allowed to set before the canal orifice was sealed with Cavit.

In the GP/EWT group, root canals were prepared with the ProFile™ GT Rotary System (Dentsply Tulsa Dental) in the crown-down fashion. Files were used from size 35/.04 to 20/.04 until loose in the canal, after which .06 taper files were used in the same fashion. Copious amounts of 5.25% sodium hypochlorite were used to irrigate the canals between each file and the canals were dried with paper points after the final irrigation. Gutta-percha cone (Dentsply International) that matched the prepared canal was chosen to produce a 'tug back'. The apical 1.0 mm of the gutta-percha cone was removed from the working length. A clean hand file that matched the final size of the working file, coated with the Kerr Pulp Canal Sealer™ EWT was taken to the working length in a circular motion to ensure complete coating of the canal walls. The selected gutta-percha cone was inserted into the canal. The Touch'n Heat 5004 instrument was used to remove excess gutta-percha, and then inserted into the canal for 3 to 4 mm and quickly withdrawn. The Schilder pluggers were immediately inserted into the canal to compact vertically the warm gutta-percha. This compaction process was repeated until the pluggers were inserted to 5 to 7 mm short of the working length. The canals were then back filled with warm gutta-percha, compacted and sealed with Cavit.

Root canal space sealing evaluation

Root sections at 2 mm from the apex were selected for the analysis of root canal space sealing by the 3 obturation systems. Images were obtained using the 3D scanning microscope at a resolution of 0.1 µm at 200x magnification and analysed using the NIH Image J software (version 1.42j). The total root canal space (T) at the cross section was calculated as the area within the root canal wall. The root canal space was divided into two areas according to the contents identified under the microscopic evaluation: area occupied by the gutta-percha and sealants (GP&S) and area identified as void and debris (V&D) (Fig 1). The unsealed space was calculated as the percentage of total root canal space occupied by voids and debris (V&D/T *100%). To assess the precision of the measurements, 20% of the images were reevaluated at a 2-week interval and the correlation coefficients of the two measurements were 0.997.

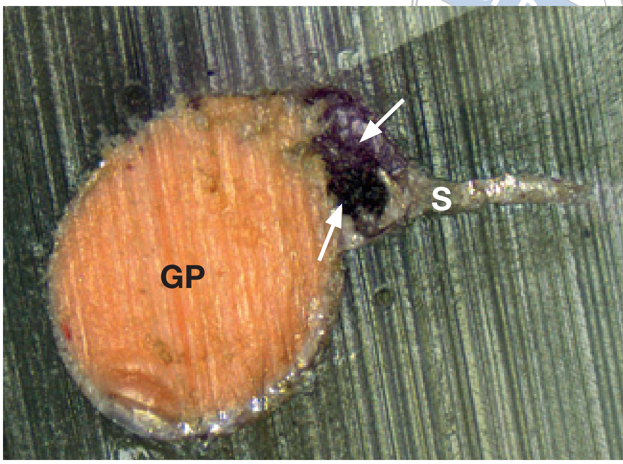

Fig 1 Assessment of root canal space occupied by voids and debris. The root canal space was divided into two areas according to the contents identified under the microscopic evaluation: area occupied by the gutta-percha (GP) and sealants (S) and area identified as void and debris (arrows). (Bar length = 100 µm)

Apical sealing study

After completing the root canal obturations, all the specimens were stored in 100% relative humidity at 37°C for 4 weeks before processing for apical leakage study. A negative control with a tightly sealed apical foramen and canal orifice and a positive control with an open foramen were included in the study. The specimens were processed following the procedures modified from those described by Zmener et al[12]. Briefly, the coronal portions of the teeth were covered with sticky wax and the root surface of each tooth was coated with 3 layers of nail varnish, leaving about 1.0 mm around the apical foramen exposed. The teeth were suspended in individual vials containing 1% basic fuchsine dye (pH 7.0)

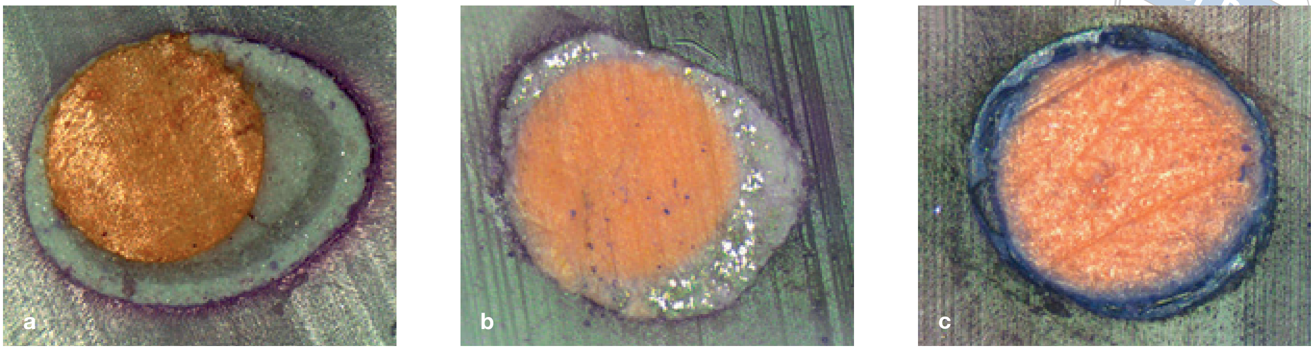

Fig 2 Typical images of dye leakage in the 3 study groups. A tight seal exists between the gutta-percha cone and the sealant in the GP/EWT (a) and the Activ GP (b) groups, with leakages occurring between the sealant and the dentinal walls. The sealant was neither bonded to the gutta-percha cone nor to the dentinal walls in the EndoRez (c) groups, resulting in dye leakages along the dentinal walls and the gutta-percha cone. (Bar length = 100 μm)

Fig 3 Apparent polymerisation shrinkage of resin sealants (S) in the canal space in the EndoRez filled root canal. The shape of the sealants' outline conforms to that of the canal wall but with a large void (V) in between. Note that dye leakages also occurred between the gutta-percha (GP) and the resin sealant. (Bar length = 100 μm)

for 7 days at 37° C. The teeth were then removed from the dye and rinsed with deionized water. The nail varnishes and wax were removed with scalpels. All specimens were embedded in clear orthodontic resin with the long axis of the tooth parallel to the resin block. Specimens were then sectioned horizontally in 1 mm increments using a precision slow speed diamond wafer saw under continuous water irrigation. The resin blocks were oriented so that the sections were perpendicular to the long axis of the tooth. Five sections at 1.0 mm apart were made from each specimen starting from the apex. Sections were then mounted on microscope slides and analysed using a focus-variation 3D scanning microscope (Alicona Imaging)[18]. Dye leakages were evaluated by two investigators blinded from the groupings of the specimens. Dye staining was noted as present or absent at each section. The last section with positive dye staining was recorded as the length of dye penetration. The two investigators performed the evaluations independent of each other and the results were compared at the completion of the evaluation. For the root sections where disagreement occurred between the two investigators with regard to the presence or absence of dye staining, a consensus was reached through discussion by the two investigators and a third investigator was then consulted to confirm the final decision.

Statistical analyses

Dye penetration lengths and the percentages of total root canal space occupied by voids and debris (V&D/T*100%) for each group were analysed for normality in distributions. The non-parametric Kruskal-Wallis tests were used when the distribution pattern deviated from normality and the analysis of variance (ANOVA) and post-hoc Tukey tests were used when the distribution conformed to normality. The proportions of canals with signs of leakage (positive dye staining) were compared among the 3 study groups using contingency table Chi-square tests. All the statistic tests were two-tailed and a P value less than 0.05 was considered statistically significant.

Results

The root canal spaces occupied by void and debris at 2 mm from the apex were 10.8% (SD 7.3%) for the GP/EWT group, 10.5% (SD 7.2%) for the Activ GP group and 22.5% for the EndoRez group ($P < 0.0001$) (ANOVA). The EndoRez group had statistically significantly more void and debris in the root canal spaces as compared to GP/EWT ($P < 0.001$) and Activ GP

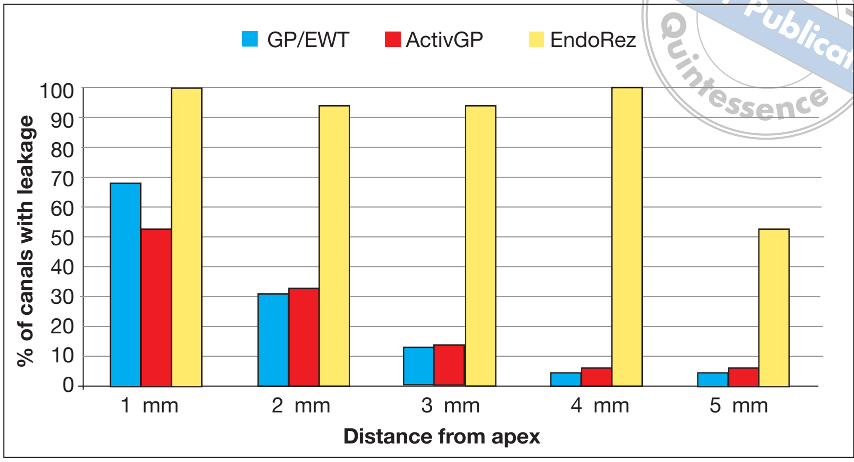

Fig 4 Percentage of root canals with dye leakages at each level of root canal sections in the 3 study groups.

($P < 0.001$) (ANOVA post hoc Tukey tests). As shown by typical images of the 3 study groups (Fig 2), the resin sealants in the EndoRez group did not achieve tight seals between the sealant and the dentinal walls, nor between the sealant and the gutta-percha cone. It appeared that the resin coating separated from the gutta-percha cone, resulting in spaces between the cone and the sealant. Dye leakages occurred not only along the root canal walls but also along the gutta-percha cones, a phenomenon not seen in the GP/EWT and the Activ GP groups. There were apparent signs of shrinkage of EndoRez sealants, leaving voids between the cured resin sealers and the canal walls (Fig 3).

Incomplete sealing of the root canal spaces was confirmed with the apical seal study, and dye penetration reached 5mm in some cases in all the 3 study groups. The dye penetration lengths (mm) are not evenly distributed among the 3 study groups, with the GP/EWT (median 1.0 mm, interquartile range or IQR 1.5 mm) and Activ GP (median 1.0 mm, IQR 1.0 mm) groups showing a shift to the left with lower lengths and the EndoRez group (median 5.0 mm, IQR 1.25 mm) showing a shift to the right with higher dye penetration lengths. The non-parametric Kruskal-Wallis tests showed that there were statistically significant differences in dye penetration length among the 3 study groups ($P < 0.0001$). EndoRez group had significantly deeper dye penetration lengths as compared to GP/EWT and Activ GP. Activ GP had similar dye penetration patterns with GP/EWT. The negative control showed no sign of dye leakage and the positive control exhibited severe staining at all levels of the sections.

There were statistically significant differences in dye leakages at each level of root canal sections among the 3 study groups (Chi-square tests, $P < 0.0001$) (Figure 4). At the section of 1.0mm from the apex, 100% of the root canals in the EndoRez group had dye leakages, as compared to 68% in the GP/EWT group and 53% in the Activ GP group ($P < 0.01$). Numbers of root canals with dye leakages reduced progressively with the increase in distance from the apex in all 3 groups. At 2 mm from the apex, approximately 32% of root canals in the GP/EWT and Activ GP groups had dye leakages as compared to 94% in the EndoRez group ($P < 0.0002$). At 5 mm from the apex, 6% of root canals in the GP/EWT and Activ GP groups had dye leakages, as compared to 53% in the EndoRez group ($P < 0.001$).

Discussion

The results of the present study indicate that none of the three root canal obturation systems could uniformly achieve a complete seal of root canal spaces *in vitro*. The glass ionomer-based obturation system Activ GP performed similarly to the vertical compaction of warm gutta-percha in terms of root canal space sealing ability, while the methacrylate resin-based obturation system EndoRez showed significantly poor apical sealing and had significantly more void and debris in the canal space than the Activ GP and the warm gutta-percha systems. At 2 mm from the apex, almost all the root canals obturated with the EndoRez system had signs of apical leakages. Apparent shrinkages of the resin sealants occurred in the EndoRez group as indicated by the presence of root canal spaces devoid of the sealants after obturation.

The findings of the present study confirmed previous reports that the methacrylate resin-based root canal obturation system, specifically the EndoRez, could not uniformly achieve a tight seal of the root canal spaces[2,14-17]. In a study comparing the sealing ability of EndoRez with a conventional gutta-percha and zinc oxide–eugenol (ZOE)-based sealant using a scanning electro microscope (SEM), it was found that 24% of the canal space was occupied by voids and debris at 2 mm from the apex in the EndoRez group, compared to 12% in the gutta-percha and ZOE group[19]. The present study confirmed this finding and found that nearly 23% of the canal spaces were voids and debris in the EndoRez group, compared to 11% in the warm gutta-percha and EWT sealer group. Using a high-resolution 3D scanning microscope, we were able to observe the specimens in true colour without the need for sample preparation and dehydration as in SEM studies, and accurately identify the locations of apical leakage in relation to the gutta-percha cones and the sealants. We found that the leakage pattern in the EndoRez group was distinctly different from that in the gutta-percha and EWT sealant group, with the former showing dye penetrations not only between the sealant and the canal wall but also between the gutta-percha cone and the sealant, while the latter showing dye penetration between the sealant and canal wall only. This finding suggests that no bonding occurred between the resin-coated gutta-percha cone and the resin-based sealant. Polymerisation shrinkage of the sealants may explain this phenomenon. It appears that the polymerised sealant pulled away from the canal wall and the gutta-percha cones, leaving voids on either side of the sealant. As a result, the EndoRez system had a significantly lower bond strength to the canal wall than that of the gutta-percha and EWT sealant group as shown by the results of push-out tests[20]. Tay et al suggested that lacking an oxygen inhibition layer on the resin-coated gutta-percha cones might have caused the weak bond between the sealant and the resin coating and that an application of a resin adhesive may improve the bonding[14]. The application of a dual-cured two-step self-etch adhesive did improve the performance of the EndoRez system in vitro and achieved an apical seal that was comparable to that of the conventional vertical compaction of warm gutta-percha[1].

The glass ionomer-based Activ GP system performed significantly better than the EndoRez system and was comparable to the conventional vertical compaction of warm gutta-percha in an apical seal. This finding corroborated to the results of push-out tests, which showed that the bond strength of Activ GP to the canal wall was significantly higher than that of the EndoRez and other resin-based obturation systems and was at least equivalent to that of the conventional gutta-percha and EWT sealant group[20]. Imaging analyses of the root canal sections also showed that a tight seal existed between the gutta-percha cones and the sealants and the apical leakage, when occurred, was located between the sealants and the canal walls as in the warm gutta-percha and EWT sealant group. No apparent shrinkages were noted of the glass ionomer-based sealants. As the gutta-percha cone in the Activ GP system is impregnated with glass ionomers, chemical bonds may have occurred between the sealant and the cone, resulting in a tight seal of the sealant-cone interface. It is unlikely that the glass ionomer-based sealant could form an adequate ionic bond between the sealant and the dentin of the canal wall[6,8]. The sealing ability of the Activ GP is at best equivalent to that of the ZOE-based EWT sealant, as shown by the apical leakage data and the proportion of voids and debris in the canal space in the present study and the previous push-out study[20]. These findings suggest that the bond between the glass ionomer-based sealant and the canal wall dentin is more likely mechanical than chemical, which is similar to that of ZOE-based sealants.

In summary, the findings of the present study indicated that polymerisation shrinkage of EndoRez, a methacrylate resin-based root canal sealant, may compromise its sealing ability and results in large voids following root canal obturation. The Activ GP, a glass ionomer-based single cone root canal obturation system, is comparable to the conventional vertical compaction of warm gutta-percha in its sealing ability.

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