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# Comparison of Epiphany® and AH-Plus® Root Canal Sealer Penetration of Dentinal Tubules: A SEM Study

A thesis submitted in partial fulfillment of the requirements for the degree of Master of  
Science in Dentistry at Virginia Commonwealth University.

by

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## Table of Contents

List of Tables .....	iv
List of Figures .....	v
Abstract .....	vii
Introduction .....	1
Methods and Materials .....	5
Results .....	9
Discussion .....	19
Vita .....	32

## List of Tables

Table	Page
Table 1: Group Assignments Based on Obturation Material and Final Ethanol Rinse.....	6

## List of Figures

Figure	Page
1. Control Group Specimen. After instrumentation and irrigation with 5.25% NaOCl and 17% EDTA, specimen was split in half for SEM analysis. SEM photomicrograph confirms smear layer removal along with open dentinal tubules. (5.75KX).....	9
2. Resilon/Epiphany® SETM Saline Final Rinse. 1 ml saline final rinse prior to obturation with Resilon/Epiphany® SETM. Specimen was subjected to micropush-out assay. No sealer observed in dentinal tubules. Failed Resilon-sealer interface observed. (1.19KX).....	10
3. GP/AH-Plus® Saline Final Rinse. 1ml of saline final rinse prior to obturation with GP/AH-Plus®. Specimen was subjected to micropush-out assay. Penetration of sealer at the canal-dentin border. Extensive sealer tags are seen penetrating deep into the dentinal tubules. The sealer appears as long smooth tubular rods. (515X).....	11
4. GP/AH-Plus® Saline Final Rinse. 1ml of saline final rinse prior to obturation with GP/AH-Plus®. Higher magnification of Figure 3. Numerous sealer tags evident throughout this photomicrograph. Sealer appears as long smooth tubular rods completely filling the dentinal tubule space. (2.61KX).....	11
5. GP/AH-Plus® 70% Ethanol Final Rinse. 1ml of 70% ethanol final rinse prior to obturation with GP/AH-Plus®. Specimen was subjected to micropush-out assay. Penetration of sealer into dentin tubules observed. Sealer appears as rods completely filling the tubule space. (921X).....	12
6. GP/AH-Plus® 70% Ethanol Final Rinse. 1ml of 70% ethanol final rinse prior to obturation with GP/AH-Plus®. Specimen was subjected to micropush-out assay. AH-Plus® seen penetrating tubules with evident sealer tags at a higher magnification. Note the mass of sealer at the sealer-dentin interface. (1.13KX)...	13

7. GP/AH Plus with 95% Ethanol Final Rinse. 1ml of 95% ethanol final rinse prior to obturation with GP/AH-Plus®. Specimen was subjected to micropush-out assay. Penetration appears “web-like” from the sealer-dentin interface. (2.60KX).....14
8. GP/AH-Plus 100% Ethanol Final Rinse. 1ml of 100% ethanol final rinse prior to obturation with GP/AH-Plus®. Specimen was subjected to micropush-out assay. Sealer penetration observed as smooth and tubular shaped rods. Not all dentin tubules are filled. Some remain un-occluded. (1.13KX).....15
9. Resilon/Epiphany® 70% Ethanol Final Rinse. 1ml of 70% ethanol final rinse prior to obturation with Resilon/Epiphany®. Specimen subjected to micropush-out assay. No sealer penetration evident. Dentinal tubules open and un-occluded. (900X).....16
10. Resilon/Epiphany 95% Ethanol Final Rinse. 1ml of 95% ethanol final rinse prior to obturation with Resilon/Epiphany®. Specimen subjected to micropush-out assay. No evidence of sealer penetration observed. Gap formations observed along the sealer-dentin interface and the Resilon-sealer interface. (582KX).....16
11. Resilon/Epiphany with 100% Ethanol Rinse. 1ml of 100% ethanol final rinse prior to obturation with Resilon/Epiphany®. Specimen was subjected to micropush-out assay. No sealer penetration evident in dentinal tubules. Gap formations observed along the sealer-dentin interface. (418X).....17
12. Resilon/Epiphany with 100% Ethanol Final Rinse. 1ml of 100% ethanol final rinse prior to obturation with Resilon/Epiphany®. Specimen was subjected to micropush-out assay. Bond failure observed at the Resilon-sealer interface. (193X).....17

## Abstract

### COMPARISON OF EPIPHANY® AND AH-PLUS® ROOT CANAL SEALER PENETRATION OF DENTINAL TUBULES: A SEM STUDY

By Kalisha Cotten Jordan, DDS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University.

Virginia Commonwealth University, 2011.

Program Director: Karan J. Replogle DDS, MS,  
Chair and Postgraduate Program Director, Endodontics

The purpose of this study was to evaluate the effect of a final rinse of ethanol on depth of sealer penetration in teeth obturated with Gutta Percha (GP)/AH-Plus® (Dentsply, De Trey GmbH, Konstanz, Germany) or Resilon/Epiphany® SE™ (Pentron Clinical Technologies, LLC, Wallingford, CT). Extracted human anterior teeth (n= 32) were shaped to size 30, 0.06 taper using nickel-titanium rotary files and subjected to an identical irrigation protocol. Specimens were randomly divided into eight groups according to final irrigating solution (saline, 70%, 95%, or 100% ethanol) and obturation material (GP/AH-Plus® or Resilon/Epiphany® SE™). A 2mm thick slice was obtained by sectioning each obturated root at 3mm and 5mm from the anatomic apex. Specimens



were cleared and assessed using scanning electron microscopy (SEM). Sealer penetration was observed at different magnifications when using GP/AH Plus<sup>®</sup> across all final rinse concentrations. Among Resilon/Epiphany<sup>®</sup> SE<sup>™</sup> groups, no sealer penetration was evident under SEM. Conclusions: 1) GP/AH-Plus<sup>®</sup> showed evidence of sealer penetration, however, Resilon/Epiphany<sup>®</sup> SE<sup>™</sup> did not show evidence of sealer penetration at both the dentin and sealer interface. 2) A final rinse with any concentration of ethanol prior to obturation does not improve sealer penetration with GP/AH-Plus<sup>®</sup> groups. 3). Resilon/Epiphany<sup>®</sup> SE<sup>™</sup> bond can be dislodged at either the interface of sealer and Resilon or dentin and Resilon.

## Introduction

Chemomechanical preparation of the root canal system prepares the canal to receive obturation material. A fluid tight seal is needed to prevent bacterial contamination of the root canal space. According to Sen et al (1), bacteria have been shown to penetrate 150 to 400µm into dentinal tubules. A seal along the length of a root canal system is achieved with a root canal sealer. An ideal sealer has the ability to aggregate the obturation material, adhere to the canal walls, and aid in the prevention of bacterial recontamination of the canal space (2).

Following instrumentation and shaping of the canal system, dentinal tubules along the canals are occluded with organic and inorganic materials described as the “smear layer” (3). Irrigation with 17% ethylenediaminetetraacetic acid (EDTA) followed by 5.25% sodium hypochlorite (NaOCl) has been shown to remove the organic and inorganic components of the smear layer (4, 5, 6-8). The organic components within the dentinal tubules have been shown to be removed by 5.25% NaOCl (4). Removal of the smear layer enhances the ability of filling materials to enter the dentinal tubules which subsequently allows greater sealer penetration into dentinal tubules (8-10).

Sonication has been used to aid in smear layer removal and has proven to significantly clean canals (11). Agitation caused by an ultrasound activated file efficiently cleans the entire length of the root canal walls. Sonication enlarges the lumen of the

dentinal tubules, which aids in removal of smear layer after instrumentation (12). Clean canals, i.e. canals with smear layer removed, enhance sealer penetration.

Penetration of sealer into the dentinal tubules prevents the dislodgement of the obturation material within the canal. Increased sealer penetration has been suggested as a mechanism that entombs any remaining bacteria preventing residual microorganisms from repopulating the canal space (8). Saleh et al (13) showed that sealer penetrates up to 300µm within the dentinal tubules and kills bacteria.

The bond formed between the root canal filling material and the canal walls is of particular importance for long-term success of root canal therapy (14, 15). Adhesion is defined as the force that binds two substances that are brought into intimate contact and is the result of attraction between molecules. Resin-based sealers purport to adhere the obturating material to dentinal walls. Resin-based sealers such as Diaket, AH-Plus®, and Epiphany® have been observed under SEM analysis to penetrate most patent dentinal tubules (1, 8). Mamootil et al (16) demonstrated that dentinal tubule penetration varied amongst the resin-based sealers and the ZnOE-based sealers. A methacrylate resin-based sealer, EndoREZ®, was shown to penetrate dentinal tubules, however, AH26™ penetrated significantly more (16).

Self-adhesive, resin-based sealers such as Epiphany® SE™ (RE/SE) (Pentron Clinical Technologies, LLC, Wallingford, CT) were introduced in 2004. Resilon is a thermoplastic synthetic polymer-based root canal filling material that has similar handling properties as gutta-percha. It is composed of polymers of polyester. It has approximately 65% filler content by weight including bioactive glass, bismuth oxychloride, and barium sulfate (17).

The sealer used in conjunction with Resilon for obturation of the root canal space is Epiphany®. Epiphany® is a self-etch dual curable composite sealer (18). It is comprised of ethoxylated glycerolate dimethacrylate (BisGMA), urethane dimethacrylate (UDMA), and hydrophilic difunctional methacrylates. The fillers, up to 70% by weight, include calcium hydroxide, barium sulfate, barium glass, and silica. One of the claims of those advocating the use of Resilon is its ability to produce a bonded monoblock filling. This is created by the adhesion of the Resilon cone to the resin based sealer, which adheres to the dentinal wall and penetrates the dentinal tubules. Shipper et al (17) suggested the formation of this monoblock provides greater resistance to microbial leakage.

AH26™ is an epoxy resin–based sealer used with gutta percha (GP). AH26™ sealer was found to release formaldehyde during setting, with maximum release after two days (19). For this reason, AH26™ was modified to AH-Plus®. AH-Plus® is a two component paste root canal sealer based on epoxide–amine resins. The manufacturer of AH-Plus® reports it has the same advantageous properties of AH26™ but preserves the chemistry of the epoxy amines more effectively and does not release compounds such as formaldehyde which are not biocompatible (20).

A sealer's chemical and physical properties are factors that determine ability of sealer to penetrate into dentinal tubules (8). Two physical properties, surface tension and wettability, play a role in the way sealer behaves. Surface tension of filling material and dentin walls determines the depth of penetration into the dentinal tubules. The lower the tension, the higher the penetration level of the sealer (21). Decreasing the surface tension of an irrigant will also improve its flow into the dentinal tubules. Tensioactive agents,

such as ethanol, were found to reduce the surface tension of NaOCl and significantly improve the ability of irrigants to spread in vitro (22). A final rinse with 95% ethanol improved sealer coverage and penetration, and significantly decreased leakage (9).

Making smear-free dentin more wettable may facilitate improved sealer penetration. Various other chemicals including 100% ethyl alcohol and 70% isopropyl alcohol have also been tested to improve dentin wettability (22, 23, and 24). Stevens et al (9) documented with SEM analysis sealer penetration into dentinal tubules when 95% ethanol was used as a final rinse prior to obturating with Roth's 801 sealer and gutta percha.

Enhancing sealer penetration may prove to dramatically improve the bond strength of a sealer to dentinal walls. The use of alcohol to aid in this endeavor should be considered. No current SEM study has simultaneously examined the sealer-dentin bond strength of obturation materials and attempted to correlate it with sealer penetration data. The authors chose to participate in a joint research venture to do so (25).

The purpose of this study was to evaluate the effect of a final rinse of ethanol on depth of sealer penetration in teeth obturated with GP/AH-Plus<sup>®</sup> or Resilon/Epiphany<sup>®</sup> SE<sup>TM</sup>. Depth of sealer penetration was evaluated under various magnifications by use of scanning electron microscopy (SEM). It was hypothesized that ethanol would improve the bond strength of AH-Plus<sup>®</sup> and Epiphany<sup>®</sup> and increase sealer penetration into the dentinal tubules.

## Methods and Materials

### **Specimen Preparation**

Thirty-two single-rooted, anterior human teeth were used in this study. All teeth collected would have been disposed of accordingly, but were kept for purposes of this study. Potential specimens for use in this study were radiographed using Dexis PerfectSize digital sensor (Dexis, Alpharetta, GA). Only anterior teeth with straight roots and small canals were selected for the study. Teeth with large canals were eliminated from the study in order to insure similar smear layers with the instrumentation protocol, i.e. presence of smear layer in all levels and on all walls. Teeth were stored in Hanks balanced salt solution (Thermo Scientific, Inc., Logan, UT) containing 0.2% sodium azide (Sigma Chemical Company, St. Louis, MO).

Teeth were accessed with a #4 round bur in a high speed handpiece with irrigation. The working length of all teeth was established by passing a #10 file to the apical foramen then reducing the length by 1.0mm. Shaping and irrigation of the canal of each specimen were accomplished in an identical manner. Briefly, canals were shaped to working length with rotary instruments of the ProTaper® series (Dentsply Tulsa Dental, Tulsa, OK), S1, S2, and F1, with the final file being a #30 0.06 taper GTX file (Dentsply Tulsa Dental, Tulsa, OK). Specimens were irrigated with 5.25% NaOCl via a #30 gauge blunt-tip needle during instrumentation. Smear layer removal was accomplished via irrigation with 4ml 17% EDTA (Endoco, Inc., Memphis, TN) followed by 4ml 5.25%

NaOCl. Sonication with the Endo Activator® followed with small 15/0.02 tips (Dentsply Tulsa Dental Specialties, Tulsa, OK) for thirty seconds after each irrigant. Canals were dried with sterile paper points following each irrigant. Cleaning, shaping, and obturation were completed by a single operator to insure consistency.

The 32 teeth were randomly divided equally into eight groups of four teeth based on obturation material to be used and irrigation protocol (Table 1). Each group received a final 1ml rinse as follows: Groups A and E, 100% Ethanol; Groups B and F, 95% Ethanol; Groups C and G, 70% Ethanol; and Groups D and H, saline (control group). The canals were subsequently dried with sterile paper points. Groups A-D were obturated using GP/AH Plus® while Groups E-H were obturated with Resilon/Epiphany®. The gutta percha used was a pre-sized cone #25 with a 0.06 taper. One additional tooth was prepared as in the control group and left unobturated for SEM analysis.

**Table 1.** Group Assignments Based on Obturation Material and Final Ethanol Rinse.

<b>GROUP ASSIGNMENTS</b>
<b>Group A (GP/AH Plus &amp; 100% Ethanol)</b>
<b>Group B (GP/AH Plus &amp; 95% Ethanol)</b>
<b>Group C (GP/AH Plus &amp; 70% Ethanol)</b>
<b>Group D (GP/AH Plus &amp; Saline)</b>
<b>Group E (RE/SE &amp; 100% Ethanol)</b>
<b>Group F (RE/SE &amp; 95% Ethanol)</b>
<b>Group G (RE/SE &amp; 70% Ethanol)</b>
<b>Group H (RE/SE &amp; Saline)</b>

Obturation of each specimen was accomplished by one operator using either GP/AH-Plus® (Dentsply, De Trey GmbH, Konstanz, Germany) or Resilon/Epiphany® SE™ (Pentron Clinical Technologies, LLC, Wallingford, CT) based on the random group

assignment. Sealer was placed on the apical ends of gutta percha or Epiphany® cones then pumped several times to coat canal walls. A heat plugger was used for downpack using System B (Analytic Technology, Redmond, WA) set at 200°C for gutta percha and 160°C for Resilon. Canals were vertically compacted leaving 5-6mm in each canal. Cotton and 3mm of Cavit™ (3M ESPE, St Paul, MN) were placed into the access preparation. Specimens were stored separately in six-well tissue culture plates for a minimum of two weeks at 37°C in an oven containing water to allow sealer to set.

### **Preparation for Micropush-out Assay**

The teeth were then prepared for a micropush-out assay prior to SEM analysis (25). Preparation of the teeth for the assay began with obtaining a 2mm thick slice by sectioning each obturated root at 3mm and 5mm from the anatomic apex using a low-speed saw (Isomet; Buehler, Ltd, Lake Bluff, IL) with a diamond disk under continuous water irrigation. The thickness of each slice was measured with a measuring caliper (Mitutoyo, Japan) and estimated within 0.1mm to ensure consistency of slices.

Slices were tested with a micropush-out technique. This was accomplished by using a 0.35mm cylindrical plunger that provided the most coverage of the root filling material without touching the canal wall. The loading of force applied to the specimen was performed on the universal testing machine (Instron Corporation, Canton, MA) at a speed of 0.5 mm/min in an apical-coronal direction to avoid any constriction interference that could be caused by root canal taper during push-out testing. The “debonding” recording operator was blinded as to which samples were tested.



Micropush-out assay was completed and results analyzed by student's *t*-test. This portion of the joint research venture was conducted by Dr. Suren Paravyan as Part 1 of this study (25).

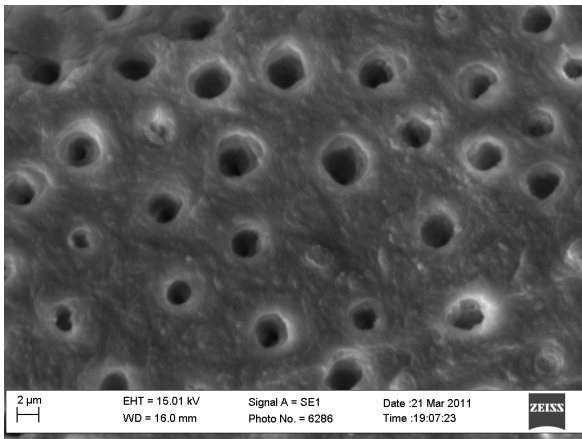
### **Scanning Electron Microscope Preparation**

Randomly selected specimens were soaked in 5.25% NaOCl for thirty minutes, then immersed in decalcifying solution (Thermo Scientific, MI) for four hours, rinsed in distilled water and allowed to dry. Specimens were mounted on aluminum stubs, sputter coated with two coats of gold (Electron Microscopy Sciences, Hatfield, PA) and evaluated at various magnifications (193X – 16.90KX) Representative images were made using Zeiss EVO50 scanning electron microscope (Carl Zeiss SMT, Inc., Peabody, MA). Specimens were evaluated for presence and location of failure of obturation seal and presence or absence of sealer penetration.

## Results

Micropush-out analysis revealed that all groups obturated with GP/AH-Plus® root fillings showed significantly higher push-out bond strength than Resilon/Epiphany® SE™ groups ( $P < .001$ ) (24). SEM analysis was conducted to determine if the significantly higher push-out bond strength could be linked to increased sealer penetration into dentinal tubules.

Ability of the smear layer removal protocol used herein was verified with SEM. This technique led to the complete removal of smear layer and debris occluding the dentinal tubules. Smear layer removal is observed (Figure 1) for the control group specimen. The dentinal tubules are open and no debris was observed. (5.75KX)



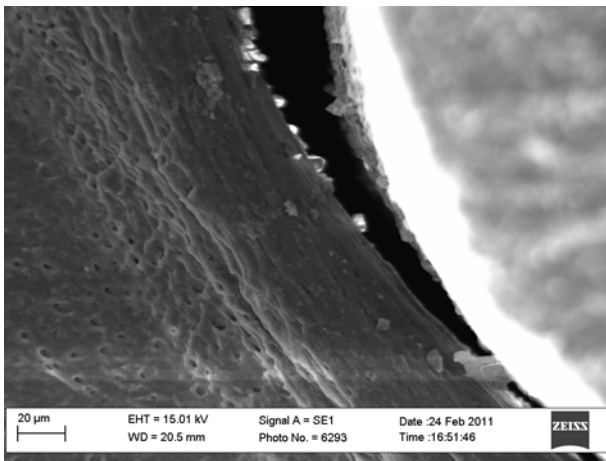
**Figure 1:** Control Group Specimen.

After instrumentation and irrigation with 5.25% NaOCl and 17% EDTA, specimen was split in half for SEM analysis. SEM photomicrograph confirms smear layer removal along with open dentinal tubules. (5.75KX)

SEM results are arranged below by groups and respective final rinse prior to obturation.

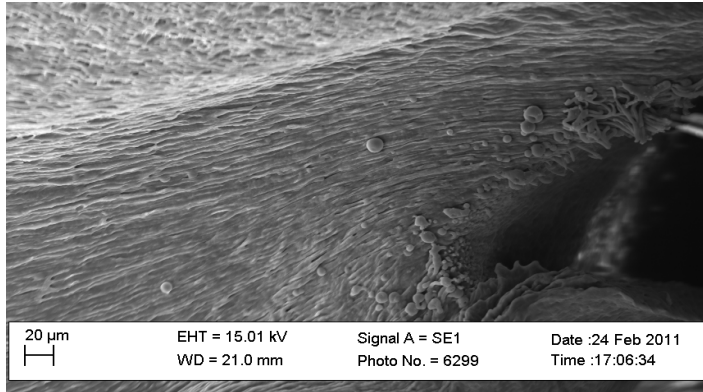
#### **Control Group (Final Saline Rinse)**

When subjected to a final rinse of saline, the Resilon/Epiphany® SE™ obturated group showed no sealer penetration. The orifices of the dentinal tubules were clean and un-filled. Bond failure was noted at the sealer-dentin interface and the Resilon-sealer interface (Figure 2). (1.91X)



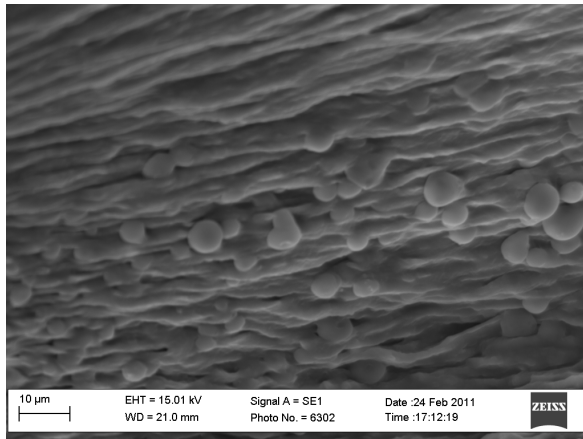
**Figure 2:** Resilon/Epiphany® SE™ Saline Final Rinse. 1ml saline final rinse prior to obturation with Resilon/Epiphany® SE™. Specimen was subjected to micropush-out assay. No sealer observed in dentinal tubules. Failed Resilon-sealer interface observed. (1.19KX)

When subjected to a final rinse of saline, the GP/AH Plus® group showed sealer penetration at the canal-dentin border. Extensive sealer tags were seen (Figure 3) penetrating deep into the dentinal tubules. Tags appear as long smooth tubular rods completely filling the dentinal tubule space at higher magnifications (Figure 4). (515X) (2.61KX)



**Figure 3:** GP/AH-Plus® Saline Final Rinse.

1ml of saline final rinse prior to obturation with GP/AH-Plus®. Specimen was subjected to micropush-out assay. Penetration of sealer at the canal-dentin border. Extensive sealer tags are seen penetrating deep into the dentinal tubules. The sealer appears as long smooth tubular rods. (515X)



**Figure 4:** GP/AH-Plus® Saline Final Rinse.

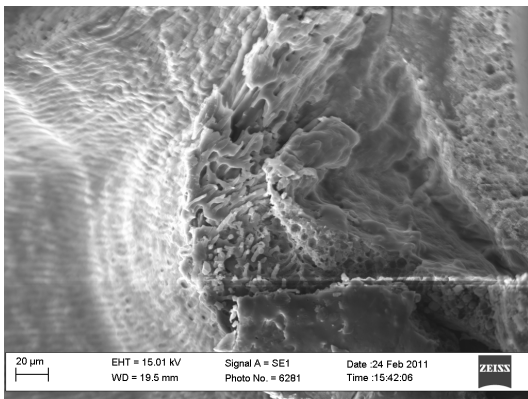
1ml of saline final rinse prior to obturation with GP/AH-Plus®. Higher magnification of Figure 3. Numerous sealer tags evident throughout this photomicrograph. Sealer appears as long smooth tubular rods completely filling the dentinal tubule space. (2.61KX)

### **Group 1 (AH Plus with final rinse of ethanol)**

SEM analysis of the GP/AH Plus® obturated group after a final rinse with 70%, 95%, and 100% ethanol, revealed that sealer penetrated into dentinal tubules. As concentration of ethanol increased, there appeared to be no corresponding increase in sealer penetration. No pattern was noted in ethanol concentration and depth of sealer penetration that might

suggest that a correlation exists between the concentration and the depth. The texture of the sealer appeared smooth, striated, and homogeneous when found in a dentinal tubule. Not all dentinal tubules were filled with sealer, some remained unoccluded. (Figures 5-8).

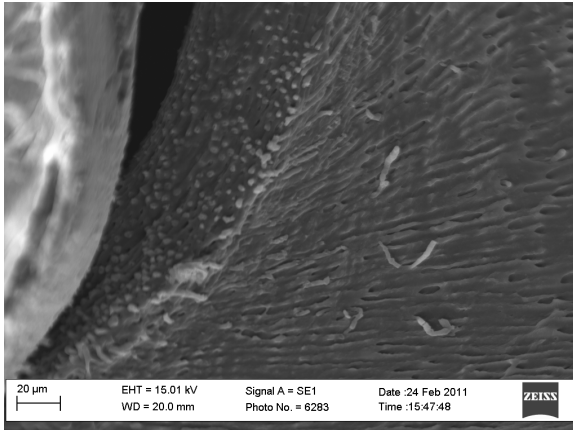
In Figure 5, the 70% ethanol final rinse resulted in sealer penetration observed as “finger-like” projections. This specimen was sectioned transversely hence the “finger-like” projections in the center of the SEM micrograph while the long extensive tubular-shaped sealer tags are observed on the left of the SEM micrograph. The dentinal tubules appear to be homogeneously filled with sealer. (921X)



**Figure 5:** GP/AH-Plus® 70% Ethanol Final Rinse.

1ml of 70% ethanol final rinse prior to obturation with GP/AH-Plus®. Specimen was subjected to micropush-out assay. Penetration of sealer into dentin tubules observed. Sealer appears as rods completely filling the tubule space. (921X)

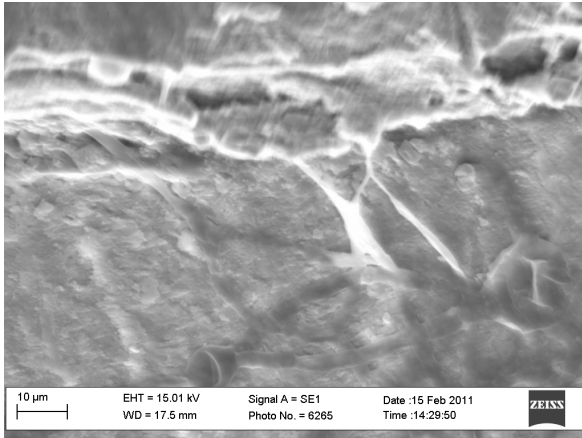
At higher magnifications of the GP/AH-Plus® group with 70% ethanol final rinse, the sealer tags appear heavily concentrated at the sealer-dentin interface (Figure 6). The tags are seen penetrating the dentinal tubules. (1.13KX)



**Figure 6:** GP/AH-Plus® 70% Ethanol Final Rinse.

1ml of 70% ethanol final rinse prior to obturation with GP/AH-Plus®. Specimen was subjected to micropush-out assay. AH-Plus® seen penetrating tubules with evident sealer tags at a higher magnification. Note the mass of sealer at the sealer-dentin interface. (1.13KX)

Sealer penetration is observed in the GP/AH-Plus® with 95% ethanol final rinse (Figure 7). The sealer tag in the center of the photomicrograph appears “web-like” at the sealer-dentin interface. Sealer penetration was also noted along the entire sealer-dentin interface in this specimen. (2.60KX)

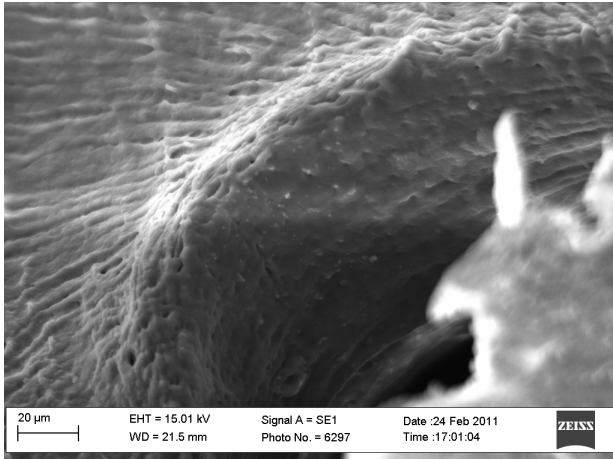


**Figure 7:** GP/AH Plus with 95% Ethanol Final Rinse.

1ml of 95% ethanol final rinse prior to obturation with GP/AH-Plus®. Specimen was subjected to micropush-out assay. Penetration appears “web-like” from the sealer-dentin interface. (2.60KX)

In the GP/AH-Plus® groups with 100% ethanol final rinse specimen (Figure 8), sealer penetration appears smooth with long tubular-shaped rods. Un-filled dentinal tubules are noted in this specimen, however, they are minimal throughout the photomicrograph.

In summary, SEM analysis of the GP/AH-Plus® groups revealed sealer penetration in all specimens examined across all concentrations of ethanol used as a final rinse. Depth of penetration varied in specimens. No pattern or consistency was noted in depth of penetration within or between groups. No statistical analysis was attempted.



**Figure 8:** GP/AH-Plus 100% Ethanol Final Rinse.

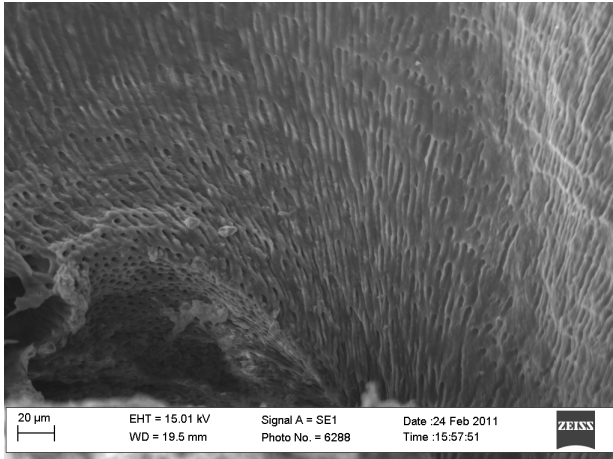
1ml of 100% ethanol final rinse prior to obturation with GP/AH-Plus®. Specimen was subjected to micropush-out assay. Sealer penetration observed as smooth tubular shaped rods. Not all dentin tubules are filled. Some remain un-occluded. (1.13KX)

### **Group 2 (Resilon/Epiphany® with final rinse of ethanol)**

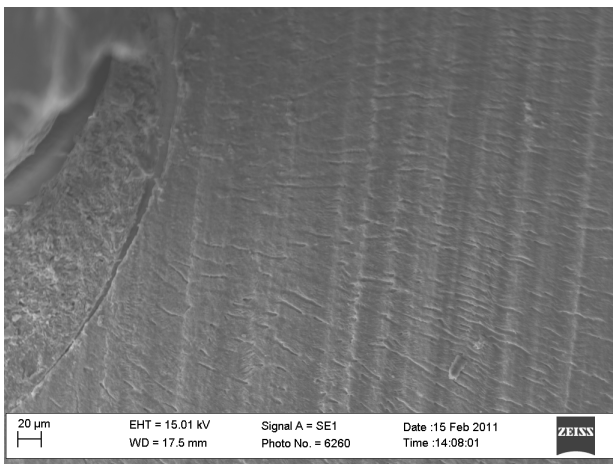
SEM analysis of Resilon/Epiphany® obturated groups with a final rinse of 70% and 95% ethanol respectively is shown in Figure 9 and Figure 10. Both photomicrographs demonstrate no penetration of sealer. Dentinal tubules are open and un-occluded. (900X)

Figure 10 denotes bond failure observed by gap formations at both the sealer-dentin interface and Resilon-sealer interface. (582KX)





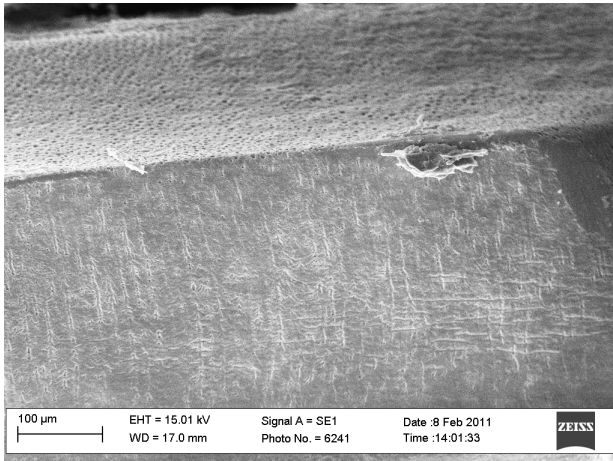
**Figure 9:** Resilon/Epiphany® 70% Ethanol Final Rinse.  
1ml of 70% ethanol final rinse prior to obturation with Resilon/Epiphany®. Specimen subjected to micropush-out assay. No sealer penetration evident. Dentinal tubules open and un-occluded. (900X)



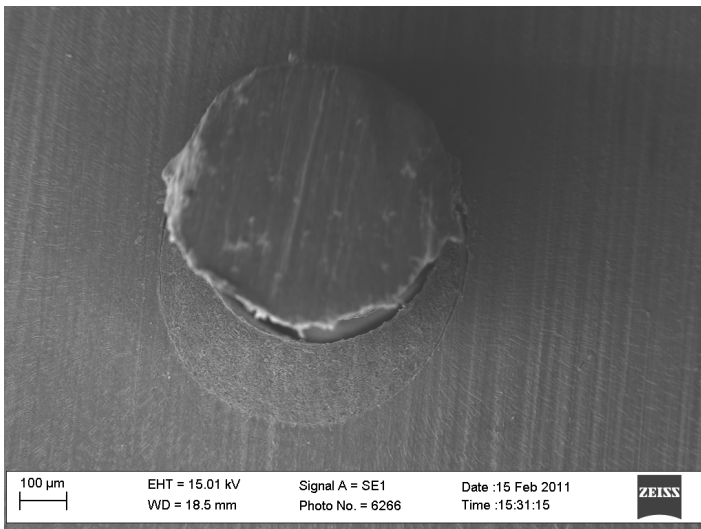
**Figure 10:** Resilon/Epiphany 95% Ethanol Final Rinse.  
1ml of 95% ethanol final rinse prior to obturation with Resilon/Epiphany®. Specimen subjected to micropush-out assay. No evidence of sealer penetration observed. Gap formations observed along the sealer-dentin interface and the Resilon-sealer interface. (582KX)

SEM analysis of Resilon/Epiphany® with a final rinse of 100% ethanol is shown in Figure 11 and Figure 12. No sealer penetration evident in the dentinal tubules or along

the sealer-dentin interface. Gap formations are observed along the sealer-dentin interface and along the Resilon-sealer interface.



**Figure 11:** Resilon/Epiphany with 100% Ethanol Rinse. 1ml of 100% ethanol final rinse prior to obturation with Resilon/Epiphany®. Specimen was subjected to micropush-out assay. No sealer penetration evident in dentinal tubules. Gap formations observed along the sealer-dentin interface. (418X)



**Figure 12:** Resilon/Epiphany with 100% Ethanol Final Rinse 1ml of 100% ethanol final rinse prior to obturation with Resilon/Epiphany®. Specimen was subjected to micropush-out assay. Bond failure observed at the Resilon-sealer interface. (193X)

In summary, SEM analysis of the Resilon/Epiphany® obturated groups across all concentrations of final rinse with ethanol showed no sealer penetration. These findings were consistent in every specimen examined. Additionally no sealer penetration was seen after a final rinse with saline. Therefore, final rinse of ethanol did not increase Epiphany® sealer penetration. In 100% of cases no sealer penetration was observed.

## Discussion

There are conflicting reports in the scientific literature regarding sealer penetration and bond strength. Some authors have concluded that the depth and consistency of a sealer's tubular penetration is influenced by the chemical and physical properties of the sealer and has no impact on bond strength (8, 16). No relationship was found to exist between bond strength and sealer penetration in a number of studies (8, 16, 26, and 27). These studies concluded that the bond strength was not higher for all sealers that were able to penetrate inside the tubules. The adhesion of sealers to gutta percha is a complex process with separate properties that affect sealer penetration (26).

In this study, there appears to be a relationship between bond strength and sealer penetration. Results of Part 1 of this study, revealed that the highest bond strengths occurred with the GP/AH plus® group when compared to Resilon/Epiphany® (25). Consequently, in Part 2 of this study, GP/AH-Plus® exhibited penetration of sealer in all groups across all concentrations. Mechanical interlocking of the AH-Plus® sealer within the dentinal tubules, which together with the cementing properties of the sealer, may have provided greater adhesion and resistance to dislodgement from dentin (25). Nunes et al (28) also found AH-Plus® to have greater adhesion to dentin when compared to Epiphany®.

In Part 1 of this study the lowest bond strengths occurred within the Resilon/Epiphany® groups (25). SEM analysis in Part 2 of this study revealed no sealer

penetration in all Resilon/Epiphany® groups across all concentrations. Sealer penetration was not measured because of lack of penetration in this group. GP/AH-plus® exhibited penetration; however, this could not be statistically compared to Resilon/Epiphany® groups, for there was no penetration.

Findings in this study are different from those of Saleh et al (26). Sealers were tested after dentinal conditioning with H3PO4, citric acid, EDTA, and distilled water. Bond strength evaluation followed by SEM evaluation revealed penetration of AH26™ into the dentinal tubules when the smear layer was removed but did not result in increased bond strength. Conversely, this study noted a trend between sealer penetration and bond strength. Sealer penetration resulted in increased bond strength. A possible explanation for the differences may be the different methodology. Saleh et al (26) studied 4mm root dentin cylinders mounted in brass holders and used a press to push the surfaces together to allow sealer to penetrate the tubules by force. In this study, traditional obturation methods were utilized using warm vertical compaction of the experimental groups with their respective sealers. Traditional methods of obturation appeared to result in adhesion of the materials to the dentinal walls in the AH-Plus® groups hence, increased bond strength. Previous studies have also shown AH26™ and AH-Plus® to penetrate into dentinal tubules (27, 30). Sevimay et al (30) found AH26™ to be the best sealer to penetrate dentinal tubules compared to a calcium hydroxide and a silicon sealer when evaluated under SEM analysis. These findings are consistent with this study's findings.

Resilon/Epiphany® was found to lack penetration across all concentrations of ethanol and the control saline groups. This group when compared to gutta percha

exhibited lower push out bond strength. Findings herein are consistent with those of Skidmore et al (29). SEM analysis revealed empty dentinal tubules after obturation with Resilon/Epiphany®. In contrast with this study, Skidmore et al found Resilon/Epiphany® to have a significantly higher bond-strength than that of gutta percha groups. Gesi et al (32) found the bond strength of the Resilon system significantly lower than that of GP/AH-Plus® which is consistent with our findings.

Methacrylate sealers have been shown to penetrate dentinal tubules in previous studies. EndoREZ® (Ultradent Products, South Jordan, UT, USA) does not have the exact components as Epiphany, however, both are methacrylate based resin sealers. Mamootil et al (16) in studying sealer penetration into dentinal tubules found that EndoREZ® penetrated the dentinal tubules extensively after smear layer removal. Both resin-based sealers, AH26™ and EndoREZ®, penetrated significantly better than ZnOE based sealers. These findings are consistent with those herein as regards AH-Plus® but not Epiphany®.

Advocates of Resilon/Epiphany have proposed that this system creates a bonded “monoblock” filling. This is created by the adhesion of the Resilon cone to the resin-based sealer, which adheres to the dentinal wall and penetrates the dentinal tubules (17, 29). Previous studies disproved this monoblock filling based on SEM analysis (15, 26, 29, and 30). Studies under SEM analysis observed bond failure to occur between the sealer-dentin interfaces termed adhesive failure (29, 31) and the Resilon-sealer interface (32). Findings of this study suggest that the weak link in Resilon-filled root canals lies at the sealer-dentin interface, which is in agreement with others (29, 33). Skidmore et al (29) determined three modes of bond failure and categorized them. Type 1, adhesive

failure, at sealer and dentin interface; type II, cohesive failure, within sealer or dentin; type III, mixed failure, failure in both the sealer and dentin. They found adhesive failure predominantly for both the Resilon and gutta percha groups with incomplete bond formation at the resin/dentin interface. This was also noted in Gesi et al (32) study. The findings herein are consistent with these findings. All groups of Resilon/Epiphany® exhibited gap formations at the sealer-dentin interface and additionally along the Resilon interface resulting in empty dentinal tubules when observed under SEM analysis. Gap formations have been suggested to occur by polymerization shrinkage of the resin sealer. This trend was observed 100% of the time in Resilon/Epiphany® specimens and was therefore not recorded (32). Under the conditions of this study, the “monoblock” theory was disproved.

Paravyan found that the push-out bond strength of the Resilon/Epiphany® groups was much lower than the GP/AH-Plus® group. This finding may be explained as a result of the drying effect of ethanol. The dry dentinal tubules may have prohibited adequate bonding and hence sealer penetration into dentinal tubules.

The manufacturer of Epiphany® recommended some important irrigation notes in the instructions for use. “Do not dessicate the canal with alcohol.” “The Epiphany® System is a wet bonding system and excessive drying will adversely affect the bond.” Under the conditions of our study, three Resilon/Epiphany® groups (70%, 95%, and 100%) were in fact desiccated with alcohol, thus adversely affecting the bond and hence no penetration of sealer. In addition to the experimental groups, the control group of saline demonstrated no sign of sealer penetration. A possible explanation for the lack of sealer penetration and decrease bond strength could be the lack of moisture due to

excessive drying of the canal space. Moisture is needed for the Resilon/Epiphany® wet bonding system.

Another plausible explanation for the significantly lower bond strength of the Resilon/Epiphany groups is the effect of the cavity configuration factors (C-Factor). High configuration factors (C- Factor) which is the ratio of bonded to unbonded resin surfaces (33) is the key factor related to polymerization stresses created by resin-based adhesives (15, 34). It is found in long, narrow canals (33). In these situations, there is very limited un-bounded surface area to provide relief from the stresses created by polymerization shrinkage (35). Methacrylate-based materials such as EndoREZ® and Resilon/Epiphany®, undergo significant volumetric shrinkage during the polymerization process (14) which is shown to be incompatible with an optimal bonding condition to the root dentin. Shrinkage leads to gap formations in the Resilon/Epiphany® groups.

Wettability of a surface has been shown to be dependent on the chemical composition of the solid surface, the roughness, and hydration state (36). The use of ethanol to lower the surface tension of the sealer and dentinal walls has been shown to increase depth of sealer penetration into the dentinal tubules (21, 22, and 30). It has been proven that the use of 95% ethanol improves sealer penetration and coverage (9). Surfactant activity was the proposed mechanism, but dentinal dehydration may be an alternative explanation, as alcohol may not change the surface composition or its roughness (24). Alcohol is considered a dehydrating medium. Dentin becomes more hydrophobic after dehydration by exposing more hydrophobic moieties and should therefore make dentin more compatible with many endodontic sealers (24, 36). However, based on the conditions of this study, it appears that ethanol did not increase sealer



penetration or bond strength into the dentinal tubules. Therefore, the question of how low must the surface tension be to allow sealer to penetrate in the Resilon/Epiphany® groups is still unanswered.

Further in vitro investigation of different sealer cements could be evaluated using this study's methodology, yet with a much larger sample size. Could a larger sample size of the Resilon/Epiphany® group allow possible sealer penetration to be observed? The authors found the results between the two experimental groups to be vastly different, therefore increasing the sample size will likely lead to the current findings of this study. Perhaps several sealer cements could be evaluated and comparisons made between bond strength and sealer penetration.

The preparation of slices for SEM analysis could be transversely prepared, therefore allowing depth of sealer penetration to be measured. Cross-sectional slices, as used in this study, were un-measurable and inconsistent. In contrast, Mamootil et al (16), sectioned specimens in cross-sections, and observed different depths of sealer penetration for the resin-based sealers as well as ZnOE based sealers. Previous studies sectioned samples for SEM analysis longitudinally (8, 9, 10, 24, and 30) and were able to measure depth of penetration in micrometers. Mamootil et al (16) argues that longitudinal sectioning does not allow for complete observation of all the dentin surrounding the canal, therefore a potential exists to miss areas of deep penetration. They recommended transverse slicing to capture the deepest areas of penetration. Specimens in this study were sliced in cross-sectional and transverse slices for part 1 of the study (25). Samples could not be measured in this dimension due to lack of consistency of sectioning. Consistent sectioning of all samples whether transverse, longitudinal, or in cross-section

would likely result in measureable depths of penetration as observed in other studies utilizing different sectioning techniques. Measuring the depth of penetration could allow comparisons to be made amongst groups. This study's results were visually vastly different. Sealer penetration was observed or it was not. Having a measurable value that could be statistically analyzed might have added validity to the data.

## Conclusion

Based on the conditions of this study, the hypothesis, that ethanol would increase AH-Plus® and Epiphany® SE™ bond strength and increase sealer penetration, is rejected. The use of ethanol to increase sealer penetration in the Resilon/Epiphany® SE™ and GP/AH-Plus® groups was not found to be successful. Resilon/Epiphany® SE™ did not penetrate the dentinal tubules across all tested concentrations. In contrast, GP/AH-Plus groups all exhibited sealer penetration into the dentinal tubules. SEM analysis revealed bond failure in the Resilon/Epiphany® group to occur consistently at both the sealer-dentin and Resilon-sealer interface.

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## Vita

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