

ASSESSMENT AND RE-TREATMENT OF RESILON OBTURATION SYSTEM
PART 1: RESILON: ASSESSMENT OF DEGRADED FILLING MATERIAL IN NON-HEALED
CASES
PART 2: RESILON: A CASE SERIES OF RETREATMENTS OF NON-HEALED CASES

Lesleigh Alexandra Payne

A thesis submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Master of Science in the Endodontics Department in the School of Dentistry.

Chapel Hill
2018

Approved by:

Peter Z. Tawil

Ashraf F. Fouad

Ceib Phillips

©2018
Lesleigh A. Payne
ALL RIGHTS RESERVED

ABSTRACT

Lesleigh Alexandra Payne: Assessment and Re-Treatment of Resilon Obturation System; Part 1: Resilon: Assessment of Degraded Filling Material in Non- Healed Cases; Part 2: Resilon: A case series of Retreatments of Non-Healed Cases
(Under the direction of Peter Z. Tawil)

Resilon obturation system was discontinued following its introduction as an alternative to traditional gutta percha and sealer. In-vitro models support anecdotal reports of degraded Resilon filling material. This may represent a significant health concern for the patient. The aim of this study was to determine the proportion of Resilon degradation in non-healed endodontic cases and to present a case series describing retreatments of non-healed Resilon obturated teeth. Patients previously treated with Resilon (R) or Gutta-Percha (GP) that had a non-healed canal that needed a retreatment were enrolled. The proportion of degraded filling material was statistically significantly different between R and GP treated groups ($p=.0003$) with 78% of R canals being degraded compared to 0% of GP canals. The difference in the proportionality of degradation between the two materials was marginally significant ($p=.054$) when dichotomized time to follow-up and presence of an orifice barrier were controlled for in the multivariate analysis.

ACKNOWLEDGEMENTS

I wish to acknowledge the following people who made this research project possible:

Dr. Peter Z. Tawil for your mentorship, friendship, and dedication.

Dr. Ashraf F. Fouad for your leadership, passion, and expertise.

Dr. Ceib Phillips for your guidance and for helping with the statistical analysis.

Dr. Krista A. Strange for your support throughout this study.

TABLE OF CONTENTS

LIST OF FIGURES.....	vii
LIST OF TABLES.....	viii
LIST OF ABBREVIATIONS.....	ix
Thesis Introduction	1
References.....	5
MANUSCRIPT 1: RESILON: ASSESSMENT OF DEGRADED	
FILLING MATERIAL IN NON-HEALED CASES.....	8
Introduction	8
Materials and Methods.....	9
Statistical Analysis.....	14
Results.....	14
Discussion	18
Conclusions.....	21
References.....	22
MANUSCRIPT 2: RESILON: A CASE SERIES OF RETREATMENTS	
OF NON-HEALED CASES	24
Introduction	24
Case Reports.....	25
Case 1	27

Case 2	30
Case 3	32
Discussion	34
References.....	37
Thesis Summary	38
References.....	41
Appendix A: Patient Consent Form	42
Appendix B: HIPAA Authorization	46
Appendix C: IRB Approval Letter	48

LIST OF FIGURES

Figure 1: Degraded Resilon filling material. Note the passive insertion of the 15K file	13
Figure 2: Intact GP filling material. Note the resistance to insertion of the 15K file resulting in bending	13
Figure 3: Radiographs and images from Case 1 (A) Pre-operative radiograph (B) Post- operative radiograph of retreatment (C) Image of Resilon in distal canals (D) Resilon debris removed with a D3 rotary instrument.....	29
Figure 4: Radiographs and images from Case 2 (A) Pre-operative radiograph (B) Post-operative radiograph of retreatment (C) Image of Resilon upon access with size 15K file being inserted passively to working length (D) Resilon debris on a size 15K file.....	31
Figure 5: Radiographs and images from Case 3 (A) Pre-operative radiograph (B) Post- operative radiograph of retreatment (C) Image of degraded Resilon in canals upon access through intraorifice barriers (D) Image of degraded Resilon in canals upon access through intraorifice barriers (E) D3 Protaper Retreatment Rotary file with Resilon debris (F) 4x4 gauze after wiping Resilon debris off of a file	33

LIST OF TABLES

Table 1: Patient demographics in the bivariate analysis where material (Resilon or gutta percha) was the explanatory variable.....	15
Table 2: Clinical characteristics in the bivariate analysis where material (Resilon or gutta percha) was the explanatory variable.....	16
Table 3: Wilcoxon Scores (Rank Sums) for variable age and time since previous treatment classified by variable material.....	16
Table 4: Degradation in the bivariate analysis where material (Resilon or gutta percha) was the explanatory variable.....	16
Table 5: Patient demographics in the bivariate analysis where degradation was the explanatory variable.....	17
Table 6: Clinical characteristics in the bivariate analysis where degradation was the explanatory variable.....	17
Table 7: Wilcoxon Scores (Rank Sums) for variable age and time since previous treatment classified by variable degraded.....	17
Table 8: Likelihood Ratio Statistics for Type 3 Analysis.....	18

LIST OF ABBREVIATIONS

AAE	American Association of Endodontists
ASA	American Society of Anesthesiologists
DMD	Doctor of Dental Medicine
ET. AL	And Others
GP	Gutta Percha
HIPPA	Health Insurance Portability and Accountability Act
IRB	Institutional Review Board
OB	Orifice Barrier
PA	Periapical Radiograph
PCL	Polycaprolactone
R	Resilon
TP_N	Time Since Previous Treatment Dichotomized at Median
UNC-SOD	University of North Carolina at Chapel Hill, School of Dentistry

THESIS INTRODUCTION

Endodontic success relies on the ability to eliminate bacteria from the root canal system and to create a fluid tight seal within the canal space (1). Endodontic therapy may be initiated for a variety of reasons including trauma, carious pulpal exposure, mechanical pulpal exposure, and restorative needs, however the goal of sealing and disinfecting the root canal system remains. Following chemomechanical preparation, adequate obturation is required to prevent future reinfection. Obturation of root canals traditionally involves the use of gutta percha in combination with a sealing cement (2). Gutta percha was first used by Bowman as a root canal filling material in 1867 and is still the most widely used obturation core in endodontics (3). Despite its popularity, the material has several shortcomings that may contribute to endodontic failure. Some of these include shrinkage after cooling and lack of adhesion that may result in bacterial leakage (4,5). Due to these shortcomings, various modifications to gutta percha have been explored to improve its physical and chemical properties. Alternatives to gutta percha have also been developed that bond to dentin to eliminate interfacial gaps and create a bacterial resistant seal (6). Still, there remains little published evidence on intracanal adhesion and the advantages/disadvantages over traditionally used gutta percha. In vitro studies have demonstrated complications with intracanal bonding including stresses due to polymerization shrinkage resulting from a high cavity configuration factor (C-factor). These shrinkage stresses

complicate the formation of high- strength bonds within the canal, which may result in decreased retention and increased marginal leakage (7,8).

Resilon is a thermoplastic synthetic polymer based root canal filling material that was introduced as a replacement for gutta percha in 2004 (9). It is composed of a parent polymer, a biodegradable aliphatic polyester called polycaprolactone, bioactive glass, methacrylate resin, barium sulphate, and bismuth oxychloride (10). Resilon handles similarly to gutta percha, and can be dissolved by solvents during retreatment (10). It is used in conjunction with Epiphany, a methacrylate- based sealer, and a self- etching primer (9). These products, when used in combination, were designed to form a monoblock with the primed dentin, resulting in an alleged superior obturation resistant to bacterial leakage (11) and increased fracture resistance of the root canal treated tooth (12).

Although initial studies showed Resilon having improved characteristics over traditional gutta percha (11,13), several in vitro studies have since reported otherwise. The idea of a monoblock has been challenged due to the unpredictability of the Epiphany/dentin bond, which was shown to result in significantly more gap formation at the dentin- sealer interface than AH Plus/ gutta percha fillings (14). In a rat subcutaneous implantation model, Resilon showed inferior long-term biocompatibility when compared to a gutta percha control (15). It is believed that Resilon's cytotoxicity may be due to its biodegradability (16). The Resilon polymeric matrix consists of 25-40% polycaprolactone (PCL) and 3-10% dimethacrylates (17-19). PCL accounts for Resilon's thermoplasticity and is susceptible to biodegradation through the cleavage of ester bonds (16). Its inclusion in the Resilon formulation has caused concern. In a series of in vitro studies, Tay et. al demonstrated the biodegradation of Resilon and PCL in the presence of abiotic factors such

as alkaline hydrolases and biotic factors including endodontically relevant bacteria and fungi (16,20,21). When compression molded into disks, both Resilon and PCL exhibited significant surface pitting and erosion compared to gutta percha following incubation in dental sludge for 4 months (16). Emulsified Resilon was shown to degrade in the presence of cholesterol esterase, a component of salivary hydrolases and an inflammatory-cell derived enzyme (20).

The significance of Resilon's susceptibility to biodegradation as demonstrated in the before mentioned studies, is its potential impact on outcome of Resilon obturated root canals. A recent study comparing long-term clinical outcomes found that Resilon had 5.7 times greater odds of failure compared with gutta percha (22). Of the Resilon obturated teeth, 56% were classified as successful compared to 88% of gutta percha obturated teeth (22). The biodegradation of Resilon as demonstrated in in vitro models may present a potential explanation for this higher clinical failure rate. Should a non-healed Resilon filled tooth require a retreatment, significant concern also exists over the increased possibility of experiencing a flare-up due to the potentially degraded status of the Resilon.

While most patients return to normal function and experience a significant relief of pain following endodontic therapy, some patients may experience an acute exacerbation of severe pain and/or swelling requiring an unscheduled visit and active treatment known as a flare-up (23). Though this occurrence is rare, it is still a significant concern for both the patient and the provider. Several factors have been recognized as predisposing patients to flare-ups. Walton and Fouad found positive correlations between flare-ups and pre-operative diagnosis of pulpal necrosis with symptomatic apical pathosis and patients with pre-operative pain and/or swelling (23). Specific bacterial species (24), periapical

radiolucencies (25), the number of visits, tooth type, allergies, and patient demographics including sex and age are all factors shown to be associated with endodontic flare-ups (26). Retreatments have also been associated with a higher prevalence of inter-appointment emergencies (26–28). Azim et al. found that previously treated teeth resulted in more than four times the rate of flare-ups compared to vital teeth (28). A study looking at retreatments of teeth with resorcinol-formaldehyde fillings noted a higher than normal incidence of flare-ups (29). These findings may be attributed to acute periapical inflammation caused by microbial factors including apical extrusion of infected debris, changes in endodontic microbiota or in environmental conditions due to incomplete chemo-mechanical preparation, increase of the oxidation- reduction potential, or due to changes in local adaptation syndrome, mechanical irritation from overinstrumentation, extrusion of irrigating solutions, or extrusion of cytotoxic filling materials (30-32).

While the Barborka et. al study identified a higher clinical failure rate of Resilon, there remains a gap in knowledge as to the cause of Resilon failures (22). The in vitro studies mentioned previously provide hypotheses including the susceptibility of Resilon and its components to degradation, however there is no previous clinical proof of this degradation. The aim of this study is to identify the proportion of degradation of Resilon filling material in non-healed retreatment cases compared to gutta percha. We also present a case series of Resilon retreatments illustrative of the clinical presentation of the material, the process of retreatment, and the occurrence of flare-ups. These findings will be significant in providing information to guide the practitioner in future treatment planning of Resilon filled teeth, such as the decision between retreatment versus periapical microsurgery.

REFERENCES

1. Dow P, Ingle J. Isotope Determination of Root Canal Failure. Oral Surgery, Oral Med Oral Pathol Oral Pathol. 1955;8(10):1100-4.
2. Prakash R, Gopikrishna V, Kandaswamy D. Gutta-percha – an untold story. Endodontology. 2005;17(2):32-6.
3. Anthony L, Grossman L. A brief history of root canal therapy in the United States. J Am Dent Assoc. 1945;32:43-50.
4. McMahon T, Zijl PCM Van, Gilad AA. Ability of new obturation materials to improve the seal of the root canal system- a review. 2015;27(3):320-31.
5. Madison S, Wilcox LR. An Evaluation of Coronal Microleakage in Endodontically Treated Teeth . Part 1. Time Periods. J Endod. 1988;14(9):455-8.
6. Schwartz RS. Adhesive Dentistry and Endodontics. Part 2: Bonding in the Root Canal System-The Promise and the Problems: A Review. J Endod. 2006;32(12):1125-34.
7. Tay F, Loushine R, Lambrechts P, Weller R, Pashley D. Geometric Factors Affecting Dentin Bonding in Root Canals: A Theoretical Modeling Approach. J Endod. 2005;31(8):584-9.
8. Bouillaguet S, Troesch S, Wataha JC, Krejci I, Meyer JM, Pashley DH. Microtensile bond strength between adhesive cements and root canal dentin. Dent Mater. 2003;19:199-205.
9. Tay FR, Pashley DH. Monoblocks in Root Canals: A Hypothetical or a Tangible Goal. J Endod. 2007;33(4):391-8.
10. Shanahan DJ, Duncan HF. Root canal filling using Resilon: A review. Br Dent J. 2011;211(2):81-8.
11. Shipper G, Orstavik D, Teixeira F, Trope M. An Evaluation of Microbial Leakage in Roots Filled with a Thermoplastic Synthetic Polymer-Based Root Canal Filling Material (Resilon). J Endod. 2004;30(5):342-7.
12. Teixeira FB, Teixeira ECN, Thompson JY, Trope M. Fracture resistance of roots endodontically treated with a new resin filling material. J Am Dent Assoc. 2004;135(5):646-52.
13. Hammad M, Qualtrough A, Silikas N. Effect of New Obturating Materials on Vertical Root Fracture Resistance of Endodontically Treated Teeth. J Endod. 2007;33(6):732-6.

14. De-Deus G, Reis C, Di Giorgi K, Brandão MC, Audi C, Fidel RAS. Interfacial adaptation of the Epiphany self-adhesive sealer to root dentin. *Oral Surgery, Oral Med Oral Pathol Oral Radiol Endodontology*. 2011;111(3):381–6.
15. Cardoso M, Marques RF, Lopes MF, Cabrita A SJ. In vivo biocompatibility of Resilon compared with gutta-percha in a pre-clinical model. *Dent Res J*. 2013;10(5):652–8.
16. Tay F, Pashley DH, Loushine R, Kuttler S, Garcia-Godoy F, King N, et al. Susceptibility of a polycaprolactone-based root canal filling material to degradation. Evidence of biodegradation from a simulated field test. *Am J Dent*. 2007;20(6):265–369.
17. Jia W, Alpert B. Root canal filling material. United States Patent Application 20030113686, US Patent & Trademark Office. 2003.
18. Jia W, Trope M, Alpert B. Dental filling material. United States Patent Application 20050069836, US Patent & Trademark Office. 2005.
19. Jia W. Dental filling material. United States Patent Application 20050066854, US Patent & Trademark Office. 2005.
20. Hiraishi N, Sadek F, King N, Ferrari M, Pashley D, Tay F. Susceptibility of a polycaprolactone- based root canal filling material to degradation using an agar-well diffusion assay. *Am J Dent*. 2008;21(2):119–23.
21. Tay F, Pashley D, Williams M, Raina R, Loushine R. Susceptibility of of a polycaprolactone- based root canal filling material to degradation. I. Alkaline hydrolysis. *J Endod*. 2005;31(8):593–8.
22. Barborka BJ, Woodmansey KF, Glickman GN, Schneiderman E, He J. Long-term Clinical Outcome of Teeth Obturated with Resilon. *J Endod*. 2017;43(4):556–60.
23. Walton R, Fouad A. Endodontic interappointment flare-Ups: A prospective study of incidence and related factors. *J Endod*. 1992;18(4):172–7.
24. Chávez De Paz Villanueva LE. *Fusobacterium nucleatum* in endodontic flare-ups. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2002;93(2):179–83.
25. Iqbal M, Kurtz E, Kohli M. Incidence and factors related to flare-ups in a graduate endodontic programme. *Int Endod J*. 2009;42(2):99–104.
26. Torabinejad M, Kettering JD, McGraw JC, Cummings RR, Dwyer TG, Tobias TS. Factors associated with endodontic interappointment emergencies of teeth with necrotic pulps. *J Endod*. 1988;14(5):261–6.

27. Imura N, Zuolo M. Factors associated with endodontic flare-ups: a prospective study. *Int Endod J*. 1995;28:261–5.
28. Azim AA, Azim KA, Abbott P V. Prevalence of inter-appointment endodontic flare-ups and host-related factors. *Clin Oral Investig*. 2017;21(3):889–94.
29. Gound TG, Marx D, Schwandt NA. Incidence of flare-ups and evaluation of quality after retreatment of resorcinol-formaldehyde resin (“Russian Red cement”) endodontic therapy. *J Endod*. 2003;29(10):624–6.
30. Siqueira J. Microbial causes of endodontic flare-ups. *Int Endod J*. 2003;36:453–63.
31. Seltzer S, Naidorf IJ. Flare-ups in endodontics: I. Etiological factors. *J Endod*. 2004;30(7):476–81.
32. Sipavičiūtė E, Manelienė R. Pain and flare-up after endodontic treatment procedures. *Balt Dent Maxillofac J*. 2014;16(1):25–30.

MANUSCRIPT 1: RESILON: ASSESSMENT OF DEGRADED FILLING MATERIAL IN NON-HEALED CASES

Introduction

Resilon is a thermoplastic synthetic polymer based root canal filling material that was introduced as a replacement for traditionally used gutta percha in 2004 (1). It is composed of a parent polymer, a biodegradable aliphatic polyester called polycaprolactone, bioactive glass, methacrylate resin, barium sulphate, and bismuth oxychloride (2). Resilon handles similarly to gutta percha, and can be dissolved by solvents during retreatment (2). It is used in conjunction with Epiphany, a methacrylate- based sealer, and a self- etching primer (1). These products, when used in combination, were designed to form an alleged monoblock with the primed dentin, resulting in a superior obturation resistant to bacterial leakage (3) and increased fracture resistance of the root canal treated tooth (4).

Although initial studies showed Resilon having improved characteristics over traditional gutta percha (3,5), several in vitro studies have since reported otherwise. The idea of a monoblock has been challenged due to the unpredictability of the Epiphany/dentin bond, which was shown by De-Deus to result in significantly more gap formation at the dentin- sealer interface than AH Plus/ gutta percha fillings (6). In a rat subcutaneous implantation model, Resilon showed inferior long- term biocompatibility when compared to a gutta percha control (7). It is believed that Resilon's cytotoxicity may be due to its biodegradability (8). The Resilon polymeric matrix consists of 25- 40% polycaprolactone (PCL) and 3- 10% dimethacrylates (9-11). PCL accounts for Resilon's

thermoplasticity and is susceptible to biodegradation through the cleavage of ester bonds (8). Its inclusion in the Resilon formulation has caused concern. In a series of in vitro studies, Tay et. al demonstrated the biodegradation of Resilon and PCL in the presence of abiotic factors such as alkaline hydrolases and biotic factors including endodontically relevant bacteria and fungi (8,12,13). When compression molded into disks, both Resilon and PCL exhibited significant surface pitting and erosion compared to gutta percha following incubation in dental sludge for 4 months (8). Emulsified Resilon was shown to degrade in the presence of cholesterol esterase, a component of salivary hydrolases and an inflammatory-cell derived enzyme (12).

The significance of Resilon's susceptibility to biodegradation as demonstrated in the before mentioned studies, is its potential impact on outcome of Resilon obturated root canals. A recent study comparing long-term clinical outcomes found that Resilon had 5.7 times greater odds of failure compared with gutta percha (14). While a higher clinical failure rate has been identified, there remains a gap in knowledge as to the cause of Resilon failures (20). The in vitro studies mentioned previously provide hypotheses including the susceptibility of Resilon and its components to degradation, however there is no previous clinical proof of this degradation. The aim of this study is to identify the proportion of degradation of Resilon filling material in non- healed retreatment cases compared to gutta percha.

Materials and Methods

Institutional Review Board approval for this clinical observational study conducted in the Graduate Endodontic Clinic at the School of Dentistry was obtained at the University

of North Carolina at Chapel Hill (#16-1069). Patients who were 18 years or older, ASA classification I or II, whose primary treatment included use of Resilon with Epiphany sealer or gutta percha and AH-Plus sealer as the obturation material, and whose treatment was completed in either the predoctoral or graduate endodontic practices at University of North Carolina School of Dentistry (UNC-SOD) during the time period of 08/2004 - 08/2013 were identified through a search of the electronic patient record. Patient's whose dental records did not objectively indicate which material was used for obturation (Resilon or gutta percha) or whose dental records did not contain an adequate post-operative radiograph of the primary root canal treatment were excluded.

Five hundred eighty patients were randomly selected from a pool of 7,376 possible patients identified in the electronic patient record search. A telephone call was made to the 580 randomly selected patients at the phone numbers registered in the database. If there was no answer, a scripted voice message was left and the secondary number on file was then called. Thirty eight patients agreed to come into the endodontic clinic for a follow-up examination. Of the 38 patients, 11 were determined to have a non-healed root canal requiring retreatment based on the follow-up examination described below.

Follow- up Examination

Follow- up examinations were performed by one of two endodontic residents at UNC-SOD under the supervision of a board certified endodontist. The patient was assigned a study ID # under which the following data were recorded on a standardized assessment form: age, gender, tooth type (anterior, premolar, molar), time since completion of previous root canal treatment, type of initial filling material (Resilon or gutta percha).

A head and neck exam and intra oral evaluation were performed. Endodontic diagnostic tests were completed including percussion and palpation testing, tooth slooth response, and probing depth measurements. A periapical radiograph (PA) was taken at an angle similar to the original post- operative radiograph. A tooth was considered non-healed if the patient presented with signs or symptoms of infection or if there was a periapical lesion of the same or larger size than in the original post-operative radiograph.

Retreatment

Patients identified as requiring retreatment were assigned to one of two endodontic residents by front desk personnel at UNC-SOD. Patients signed the standardized UNC-SOD consent form for endodontic treatment as well as consent to participate in the study and HIPAA Authorization. Patients were given the opportunity to ask the investigator questions concerning treatment. The retreatment began with local anesthesia based on the individual needs of the subject. The investigator isolated the tooth to be retreated with a single punch rubber dam. The rubber dam was disinfected before and after access with 4% NaOCl. After adequate anesthesia and isolation, the investigator removed any carious tooth structure or compromised restorations. The tooth was then accessed to expose the filling material. Upon access of the root canal system, the investigator classified the Resilon or gutta percha filling material in each canal as either degraded or intact. Classification was based on the following criteria:

- **Degraded:** Lack of solid dense material remaining within the canal confirmed by passively placing a size 15 K file into the canal space (i.e. it does not cause

bending of the size 15 K file) (Fig.1).

- **Intact:** Presence of solid dense filling material that provides resistance to size 15 K file insertion resulting in the file bending (Fig. 2).

The following clinical observations were recorded during treatment for each tooth:

- Type of restoration (full coverage or not)
- Presence of caries
- Presence of a missed canal
- Apical stop
- Tooth discoloration
- Presence of an orifice barrier

After documentation of the findings, the investigator continued with the retreatment, which was completed over two-visits with inter-appointment calcium hydroxide.

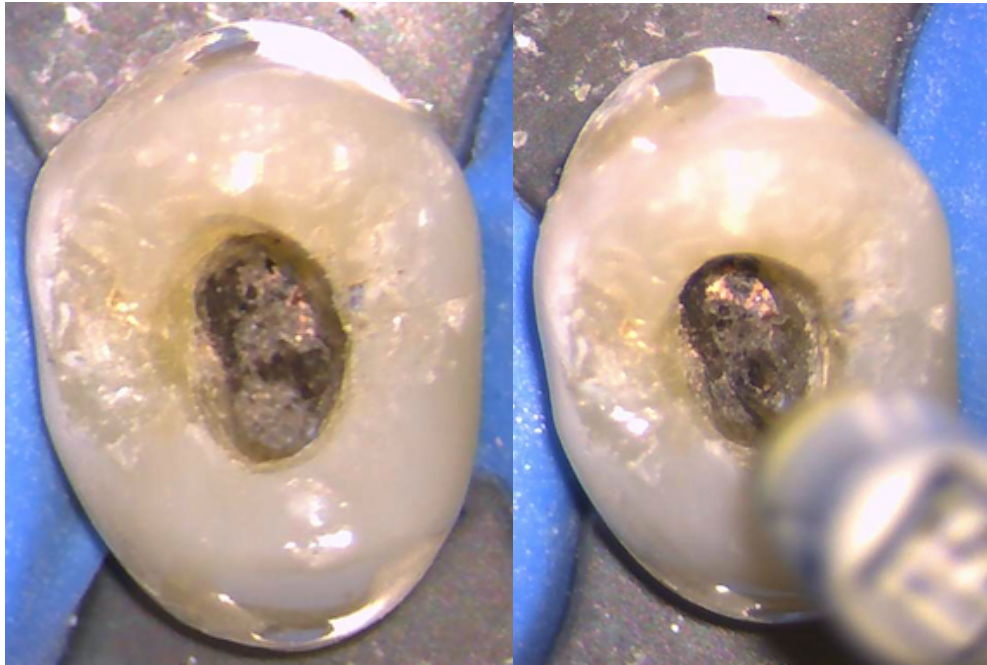


Figure 1: Degraded Resilon filling material. Note the passive insertion of the 15K file

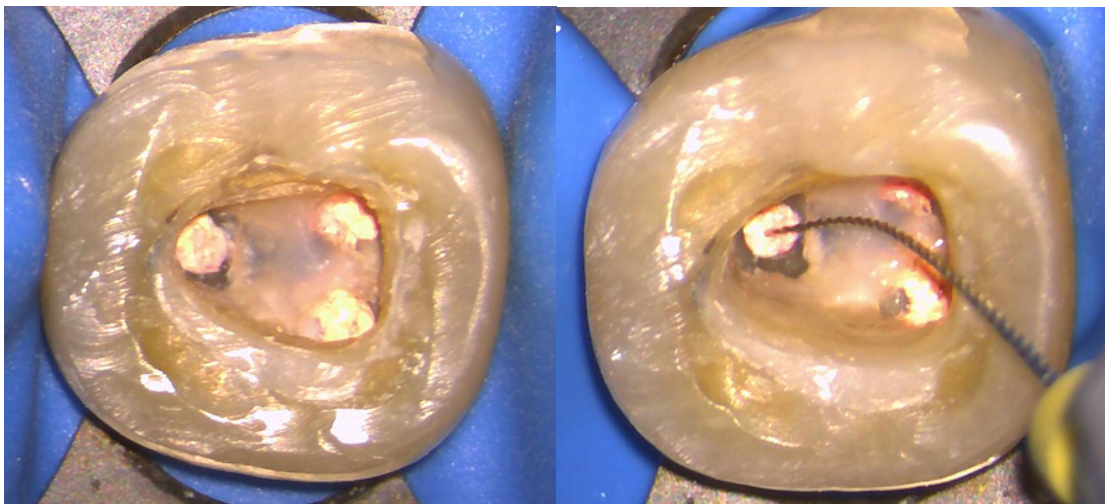


Figure 2: Intact GP filling material. Note the resistance to insertion of the 15K file resulting in bending

Statistical Analysis

A power analysis indicated that a Fisher's exact test with a 0.05 two-sided significance level would have greater than 80% power to detect a difference in proportions of 0.70 when the sample size in each group was 10.

Fisher's exact test was used to compare the demographics and clinical characteristics of the two materials (Resilon or gutta percha) and to assess the effect of material and demographics and clinical characteristics on the presence of degradation. Logistic Regression using likelihood ratio tests in PROC GENMOD (SAS ® Vers 9.3) was used to assess the effect of three variables (obturation material, presence of an orifice barrier, and time since previous treatment dichotomized at the median time of all subjects (TP_N)) on the presence of degradation. The level of significance was established at $p < .05$.

Results

Out of 38 patients who received a follow-up examination, 11 met the criteria for inclusion, totaling 26 previously treated canals (18 Resilon and 8 gutta percha). Patients were predominately female with a median age of 65 years old with molar teeth requiring retreatment. Patient demographics (Table 1) and clinical characteristics (Table 2) including presence of a full coverage restoration, caries, missed canals, and apical stop were not found to be statistically significantly different between obturation materials in the bivariate analysis ($p > .05$). Dichotomized time since previous treatment (Table 3) and presence of an orifice barrier (Table 2) were statistically different between the two material groups ($p < .05$). The proportion of degradation between the two materials was statistically significant ($p = .0003$) with Resilon having a higher likelihood of degradation than gutta

percha in the bivariate analysis (Table 4). Of the Resilon obturated canals, 78% were degraded compared to 0% of the gutta percha canals. The bivariate analysis indicated a statistically significant difference in the periapical diagnosis between Resilon and gutta percha obturated canals at the primary treatment appointment with a higher proportion of chronic apical abscesses and asymptomatic apical periodontitis among Resilon canals ($p < .05$). However, the data was too sparse to include in the logistic regression. In the bivariate analysis where degradation was the outcome, presence of an orifice barrier (Table 6) was the only variable that was statistically significantly different between degraded and intact canals ($p < .05$) (Table 5-7). The multivariate analysis indicated that neither presence of an orifice barrier nor dichotomized time to follow-up were associated with degradation (Table 8). The difference in the proportionality of degradation between the two materials was marginally significant ($p = .054$) when the dichotomized time to follow up and presence of an orifice barrier were controlled for (Table 8).

Material	Gender		Tooth Type		
	Male	Female	Anterior	Premolar	Molar
Resilon	3 (33%)	6 (67%)	2 (11%)	5 (28%)	11 (61%)
Gutta Percha	1 (33%)	2 (67%)	0 (0%)	0 (0%)	8 (100%)
p- value		0.99			0.15

Table 1: Patient demographics in the bivariate analysis where material (Resilon or gutta percha) was the explanatory variable

Material	Full Coverage Restoration		Apical Stop		Caries		Orifice Barrier		Missed Canal	
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Resilon	14 (78%)	4 (22%)	17 (94%)	1 (6%)	3 (17%)	15 (83%)	9 (50%)	9 (50%)	1 (6%)	17 (94%)
Gutta percha	8 (100%)	0 (0%)	8 (100%)	0 (0%)	3 (38%)	5 (62%)	0 (0%)	8 (100%)	2 (25%)	6 (75%)
P-Value		0.28		0.99		0.33		0.02		0.22

Table 2: Clinical characteristics in the bivariate analysis where material (Resilon or gutta percha) was the explanatory variable

Material	Variable	Lower Quartile	Median	Upper Quartile
Resilon	Age	48	64	69
	TP	96	99	142
Gutta Percha	Age	51	68	68.5
	TP	50	84	99
P-value	Age		0.58	
	TP		0.04	

Table 3: Wilcoxon Scores (Rank Sums) for variable age and time since previous treatment classified by variable material

Material	Degraded	Intact
Resilon	14 (78%)	4 (22%)
Gutta Percha	0 (0%)	8 (100%)
P-Value		0.0003

Table 4: Degradation in the bivariate analysis where material (Resilon or gutta percha) was the explanatory variable

Degradation Status	Gender		Tooth Type		
	Male	Female	Anterior	Premolar	Molar
Degraded	5 (36%)	9 (64%)	2 (14%)	4 (29%)	8 (57%)
Intact	6 (50%)	6 (50%)	0 (0%)	1 (8%)	11 (92%)
p- value		0.69			0.13

Table 5: Patient demographics in the bivariate analysis where degradation was the explanatory variable

Degradation Status	Full Coverage Restoration		Apical Stop		Caries		Orifice Barrier		Missed Canal	
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Degraded	12 (86%)	2 (14%)	13 (93%)	1 (7%)	1 (7%)	13 (93%)	8 (57%)	6 (43%)	1 (7%)	13 (93%)
Intact	10 (83%)	2 (17%)	12 (100%)	0 (0%)	5 (42%)	7 (58%)	1 (8%)	11 (92%)	2 (7%)	10 (83%)
P-Value		0.99		0.99		0.07		.015		0.58

Table 6: Clinical characteristics in the bivariate analysis where degradation was the explanatory variable

Degradation Status	Variable	Lower Quartile	Median	Upper Quartile
Degraded	Age	48	63	69
	TP	96	96	142
Intact	Age	54	67	68.5
	TP	54	84	108
P-value	Age		0.30	
	TP		0.13	

Table 7: Wilcoxon Scores (Rank Sums) for variable age and time since previous treatment classified by variable degraded

Source	DF	Chi- Square	Pr>ChiSq
Material	1	3.7	0.054
tp_n	1	2.46	0.12
OB	1	3.55	0.06

Table 8: Likelihood Ratio Statistics for Type 3 Analysis

Discussion

The Resilon/ Epiphany obturation system serves as an example as to the difficulties surrounding bonded obturation materials. There remains little published evidence on intracanal adhesion and the advantages/ disadvantages over traditionally used gutta percha. In vitro studies have demonstrated complications with intracanal bonding including stresses due to polymerization shrinkage resulting from a high cavity configuration factor (C-factor). These shrinkage stresses complicate the formation of high-strength bonds within the canal resulting in decreased retention and increased marginal leakage (15, 16). While initial in vitro studies showed promising results including improved fracture resistance and less bacterial leakage of Resilon obturated root canals (3,4), later studies showed less favorable results including degradation of Resilon and its components as well as diminishing biocompatibility over time (6,7). While Resilon is no longer in use clinically, its effects resonate in the patients who have retained Resilon obturated root canal treated teeth.

In the present study, non-healed cases obturated with Resilon had a higher proportion of degradation (78%) compared to those obturated with gutta percha (0%). One potential explanation for the higher proportion of degradation may be the inclusion of

polycaprolactone (PCL) in the Resilon formulation. PCL is a biodegradable polyester responsible for Resilon's thermoplasticity (8). This resorbable polymer has traditionally been used as a component in drug-delivery devices due to its low melting point, biocompatibility, and susceptibility to biodegradation by enzymes and microorganisms (17). Hydrolases released by bacteria, yeast and fungi can degrade PCL through the cleavage of ester bonds (18). In a series of in vitro studies, Tay et. al demonstrated the biodegradation of Resilon and PCL in the presence of abiotic factors such as alkaline hydrolases and biotic factors including endodontically relevant bacteria and fungi (8,12,18). Following exposure to dental sludge consisting of saliva, sputum, coagulated blood, plaque and calculus, enamel, dentin and shavings from restorative procedures, compression molded disks of Resilon and PCL both exhibited significant surface degradation compared to gutta percha (8). Emulsified Resilon was shown to degrade in the presence of cholesterol esterase, a component of salivary hydrolases and an inflammatory – cell derived enzyme (12). Penetration of the coronal and apical seals could result in exposure of the Resilon filling material to this enzyme (12). Gutta percha and its main constituent poly(*trans*-1,4-isoprene) in comparison, have not been associated with biodegradation by microbial enzymes (19).

The significance of Resilon's susceptibility to biodegradation as demonstrated in this study is its potential impact on outcome of Resilon obturated root canals. A study comparing Resilon and gutta percha obturated root canals with follow- up times ranging from 2-25 months indicated statistically indistinguishable differences in clinical outcome between the two materials (20). A more recent study comparing Resilon and gutta percha cases with a mean recall time of 5.8 years and 6.6 years respectively, found a statistically significant

difference in outcome. Of the Resilon obturated teeth, 56% were classified as successful compared to 88% of gutta percha obturated teeth (14). With comparable protocol and success criteria, it is likely that the significant factor between these two studies is the time to follow-up. Should the inferior clinical outcome of Resilon be related to its biodegradation, time may prove to be a significant variable in the process. Due to the small N number in our study, we were unable to determine the full effect of time on degradation status, thus further studies are needed to determine the significance of this factor.

Within the limitations of this study, it was determined that the presence of an orifice barrier was not protective against degradation. There may be several explanations for these findings. Orifice barriers have been shown to result in coronal leakage of varying degrees based on material and thickness (21, 22). An alternative explanation is that the source of enzymatic degradation is apical. Resilon has been shown to exhibit degradation in the presence of cholesterol esterase, a component of salivary hydrolases and an inflammatory- cell derived enzyme (12). Monocyte-derived macrophages that secrete these enzymes have been shown to be present within periapical granulomas associated with endodontically infected teeth (23).

While our study demonstrates a higher proportion of degradation of Resilon obturated non-healed root canals compared to gutta percha obturated canals, further investigation should focus on the analysis of the degraded material to identify its chemical and microbiological content. This may provide us with better understanding as to the cause of biodegradation and its potential impact on the patient's health. It is also important to detect factors associated with non-healed degraded cases such as periapical status, quality of coronal seal, and radiographic appearance in order to identify teeth with greater likelihood of degradation. When considering the lack of clinical data surrounding Resilon before its acceptance by the dental community,

some concern exists. Resilon should serve as a reminder to stress the need for clinical outcome studies in the implementation of new products.

Conclusions

Within the limitations of this clinical observational study, the results indicate that Resilon with Epiphany sealer has a higher proportion of degradation when compared to gutta percha and sealer after adjusting for presence of an orifice barrier and dichotomized at median time since previous treatment. Further studies are needed to assess the effect of time on degradation and to analyze the degraded material to identify its chemical and microbiological content.

REFERENCES

1. Tay FR, Pashley DH. Monoblocks in Root Canals: A Hypothetical or a Tangible Goal. *J Endod.* 2007;33(4):391–8.
2. Shanahan DJ, Duncan HF. Root canal filling using Resilon: A review. *Br Dent J.* 2011;211(2):81–8.
3. Shipper G, Orstavik D, Teixeira F, Trope M. An Evaluation of Microbial Leakage in Roots Filled with a Thermoplastic Synthetic Polymer-Based Root Canal Filling Material (Resilon). *J Endod.* 2004;30(5):342–7.
4. Teixeira FB, Teixeira ECN, Thompson JY, Trope M. Fracture resistance of roots endodontically treated with a new resin filling material. *J Am Dent Assoc.* 2004;135(5):646–52.
5. Hammad M, Qualtrough A, Silikas N. Effect of New Obturating Materials on Vertical Root Fracture Resistance of Endodontically Treated Teeth. *J Endod.* 2007;33(6):732–6.
6. De-Deus G, Reis C, Di Giorgi K, Brandão MC, Audi C, Fidel RAS. Interfacial adaptation of the Epiphany self-adhesive sealer to root dentin. *Oral Surgery, Oral Med Oral Pathol Oral Radiol Endodontology.* 2011;111(3):381–6.
7. Cardoso M, Marques RF, Lopes MF, Cabrita A SJ. In vivo biocompatibility of Resilon compared with gutta-percha in a pre-clinical model. *Dent Res J.* 2013;10(5):652–8.
8. Tay F, Pashley DH, Loushine R, Kuttler S, Garcia-Godoy F, King N, et al. Susceptibility of a polycaprolactone-based root canal filling material to degradation. Evidence of biodegradation from a simulated field test. *Am J Dent.* 2007;20(6):265–369.
9. Jia W, Alpert B. Root canal filling material. United States Patent Application 20030113686, US Patent & Trademark Office. 2003.
10. Jia W, Trope M, Alpert B. Dental filling material. United States Patent Application 20050069836, US Patent & Trademark Office. 2005.
11. Jia W. Dental filling material. United States Patent Application 20050066854, US Patent & Trademark Office. 2005.
12. Hiraishi N, Sadek F, King N, Ferrari M, Pashley D, Tay F. Susceptability of a polycaprolactone- based root canal filling material to degradation using an agar-well diffusion assay. *Am J Dent.* 2008;21(2):119–23.

13. Tay F, Pashley D, Williams M, Raina R, Loushine R. Susceptibility of of a polycaprolactone- based root canal filling material to degradation. I. Alkaline hydrolysis. *J Endod.* 2005;31(8):593–8.
14. Barborka BJ, Woodmansey KF, Glickman GN, Schneiderman E, He J. Long-term Clinical Outcome of Teeth Obturated with Resilon. *J Endod.* 2017;43(4):556–60.
15. Tay F, Loushine R, Lambrechts P, Weller R, Pashley D. Geometric Factors Affecting Dentin Bonding in Root Canals: A Theoretical Modeling Approach. *J Endod.* 2005;31(8):584–9.
16. Bouillaguet S, Troesch S, Wataha JC, Krejci I, Meyer JM, Pashley DH. Microtensile bond strength between adhesive cements and root canal dentin. *Dent Mater.* 2003;19:199–205.
17. Woodruff MA, Hutmacher DW. The return of a forgotten polymer - Polycaprolactone in the 21st century. *Prog Polym Sci.* 2010;35(10):1217–56.
18. Lefèvre C, Tidjani A, Vander Wauven C, David C. The interaction mechanism between microorganisms and substrate in the biodegradation of polycaprolactone. *J Appl Polym Sci.* 2002;83(6):1334–40.
19. Rose K, Steinbu A. Minireviews. Biodegradation of Natural Rubber and Related Compounds : Recent Insights into a Hardly Understood Catabolic Capability of Microorganisms. *Appl Environ Microbiol.* 2005;71(6):2803–12.
20. Cotton TP, Schindler WG, Schwartz SA, Watson WR, Hargreaves KM. A Retrospective Study Comparing Clinical Outcomes after Obturation with Resilon/Epiphany or Gutta-Percha/Kerr Sealer. *J Endod.* 2008;34(7):789–97.
21. Ghulman MA, Gomaa M. Effect of intra-orifice depth on sealing ability of four materials in the orifices of root-filled teeth: An ex-vivo study. *Int J Dent.* 2012;2012.
22. Yavari H, Samiei M, Eskandarinezhad M, Shahi S, Aghazadeh M, Pasvey Y. An in vitro comparison of coronal microleakage of three orifice barriers filling materials. *Iran Endod J.* 2012;7(3):156–60.
23. Stern MH, Dreizen S, Mackler BF, Selbst AG, Levy BM. Quantitative analysis of cellular composition of human periapical granuloma. *J Endod* 1981;7:117–22.

MANUSCRIPT 2: RESILON: A CASE SERIES OF RETREATMENTS OF NON-HEALED CASES

Introduction

Resilon is a thermoplastic synthetic polymer based root canal filling material that was introduced as a replacement for traditionally used gutta percha in 2004 (1). When used in combination with Epiphany sealer and a self-etching primer, Resilon was designed to form an alleged monoblock with dentin, aiming for a superior obturation resistant to bacterial leakage (2) and increased fracture resistance of the root canal treated tooth (3).

Although initial studies showed Resilon having improved characteristics over gutta percha (2-4), several investigators began publishing in vitro studies demonstrating the biodegradation of Resilon in the presence of abiotic factors such as alkaline hydrolases and biotic factors including endodontically relevant bacteria and fungi (5-7). This is likely attributed to the inclusion of polycaprolactone, a biodegradable aliphatic polyester, in the Resilon formulation (5). PCL accounts for Resilon's thermoplasticity and is susceptible to biodegradation through the cleavage of ester bonds (5). Degradation of Resilon may be a contributing factor to its higher clinical failure rate reported in a recent study comparing long-term clinical outcomes of Resilon and gutta percha obturated root canals (8).

Should a non-healed Resilon filled tooth require a retreatment, significant concern also exists over the increased potential for flare-ups due to the potentially degraded status of the Resilon. While most patients return to normal function and experience a significant

relief of pain following endodontic therapy, some patients may experience an acute exacerbation of severe pain and/or swelling requiring an unscheduled visit and active treatment known as a flare-up (9). Retreatments in particular have been associated with a higher prevalence of inter-appointment emergencies (10–12). A study looking at retreatments of teeth with resorcinol-formaldehyde fillings noted a significantly higher than normal incidence of flare-ups (13). Due to the potential biodegradation of Resilon within the root canal, Resilon retreatments may present with comparable flare-up incidence to paste retreatments.

Throughout the literature, there is still little information to guide clinicians on the retreatment of Resilon cases including clinical presentation, challenges with removal, and flare-ups. This series aims to contribute to the knowledge of the clinical approaches of Resilon retreatments by describing three clinical cases.

Case Reports

This article describes three cases of Resilon retreatments performed at the Graduate Endodontic Department at the University of North Carolina School of Dentistry (UNC-SOD). Each case described was obturated previously with Resilon/Epiphany according to the Electronic Patient Record. Clinical and radiographic exams were performed along with endodontic diagnostic testing at a consultation visit, and each case was recommended for retreatment due to the patient presenting with clinical signs or symptoms or an enlarging periapical radiolucency. All retreatments were performed under adequate anesthesia and rubber dam isolation with the consent of the patient. Upon access of the previous Resilon

filling material, the same instrumentation and irrigation protocol was used to remove the existing Resilon and clean/shape the canals. This protocol is described below:

A 15K file was used to obtain an apical glide path and determine working length (WL) using an ApexID apex locator. Protaper Universal retreatment rotary instruments were used in the coronal and middle third of the canals. Hedstrom files were used to remove Resilon from the apical third of the canals. Irrigation involved the use of 4% NaOCl with activation using an EndoActivator. No solvents were used in removal of the Resilon. Vortex Blue files were used sequentially to enlarge and shape the canals with recapitulation with a size 10K file and 4% NaOCl irrigation between files. A final rinse was performed using 4% NaOCl and 17% EDTA. The canals were dried with paper points and calcium hydroxide was placed to WL with a Lentulo spiral. A piece of sponge was placed over the orifices followed by Cavit and FUJI 9 to seal the access.

At the conclusion of the first visit, the patient was provided with the following post-operative instructions:

- It is normal for the tooth and the area around the tooth to be sore for the first 24-48 hours
- This soreness should not be more than an over-the-counter analgesic can control ex: ibuprofen 600mg

Contact me if:

- The pain is severe and cannot be controlled by over-the-counter analgesics
- The pain is persisting or increasing
- You notice any swelling developing or increasing
- You have any further questions or concerns

A flare-up was defined as the patient experiencing an acute exacerbation of severe pain and/or swelling requiring an unscheduled visit and active treatment. If a patient experienced a flare-up, it was recorded.

At the next scheduled appointment, the root canal was obturated with gutta percha and AH Plus sealer using the warm vertical technique and the retreatment was completed. Described in detail below is the clinical presentation of Resilon including the pattern of degradation, as well as descriptions of its removal and technical challenges, and the occurrence of flare-ups.

Case 1

A 49-year-old Hispanic female with medical history including lower back pain for which she takes ibuprofen 600mg and a thyroidectomy in 2015 for which she takes Levothyroxine 100 mcg/day presented to UNC-SOD. Tooth #19 was previously root canal treated 5 years prior. Clinically #19 presented with intact porcelain fused to metal crown and composite core build-up. The diagnosis was as follows: previously treated, symptomatic apical periodontitis.

Upon access, four canals were located, two mesial and two distal canals which shared a common orifice. The round bur made a drop into the canals upon penetration of the composite and a potent smell was immediately evident. The Resilon in all four canals was similar in consistency and coloration, presenting as soft and degraded with predominately gray coloration with light pink material intermixed (Fig. 3C). A 15 K file was inserted into the canals and was able to be immediately inserted to working length passively without the use of solvents or heat. While using the Protaper Universal

Retreatment Rotary instruments to auger Resilon from the coronal and middle thirds, the material wrapped around the files in ribbons and travelled coronally where it could be removed from the canals in segments (Fig. 3D). The rotary was circumferentially scraped along the walls of the canals and was able to remove the bulk of the material, however a gray film was smeared around the canal walls and could not be removed with instrumentation. A Hedstrom was scraped along the walls and in the apical third, to remove the remaining material, but the film along the walls remained. The texture and density of the Resilon was consistent throughout the entire length of the canals. The smeared layer of Resilon was not loosened from the canal walls until the sonic activator was used in each canal with NaOCl. During activation, the irrigant turned gray and small debris could be seen floating. After a rinse with NaOCl and EDTA, the majority of the walls were residue free and clean. Some extrusion of the material was noted radiographically. Following the initial retreatment visit, the patient did not experience a flare-up.

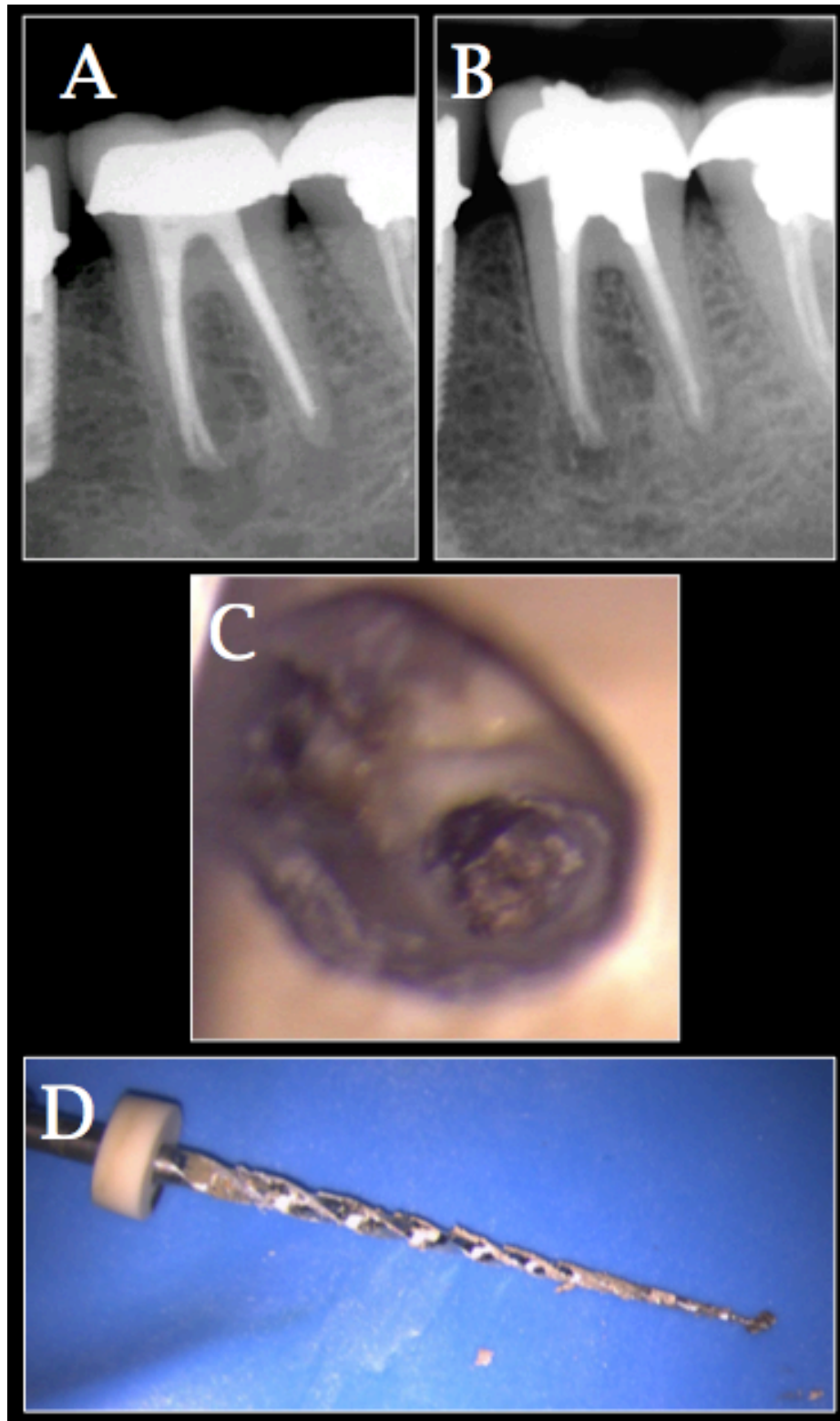


Figure 3: Radiographs and images from Case 1 (A) Pre-operative radiograph
 (B) Post- operative radiograph of retreatment (C) Image of Resilon in distal canals
 (D) Resilon debris removed with a D3 rotary instrument

Case 2

A 43-year-old Caucasian female with non-contributory medical history presented to UNC-SOD. Tooth #8 received primary root canal therapy 12 years prior. The patient presented with a lingual IRM with clinically open margins that was placed at the time of treatment. The crown was discolored with a gray hue compared to the adjacent teeth. The diagnosis was as follows: previously treated, symptomatic apical periodontitis.

Upon removal of the IRM, a very potent smell was noted. The walls of the chamber were stained gray. The consistency of the Resilon was particularly soft and mushy, with a similar consistency of a wet paste (Fig 4C). It was gray in coloration intermixed with white flecks. After removing the 15K file that was passively inserted to working length, a wet gray residue was noted that stuck to the flutes (Fig. 4D). Rather than coming out in ribbons or segments when using the retreatment rotary instrument and Hedstroms, the material seemed to mush together and create a sludge within the canal. This was removed more effectively with NaOCl irrigation and EndoActivator than with instrumentation, which made the material smear along the canal walls. Some extrusion of the material was noted radiographically. Following the initial retreatment visit, the patient did not experience a flare-up.

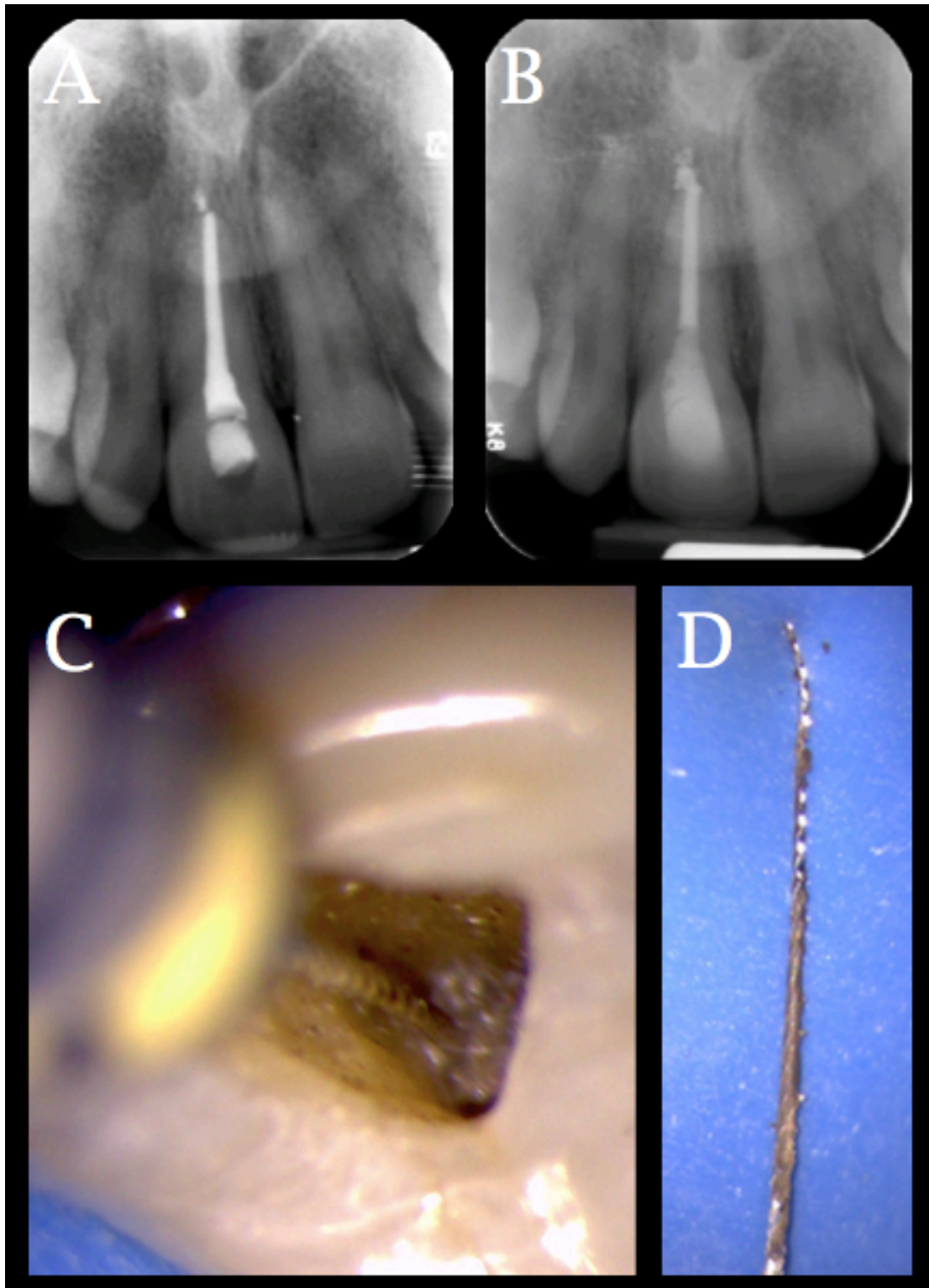


Figure 4: Radiographs and images from Case 2 (A) Pre-operative radiograph (B) Post-operative radiograph of retreatment (C) Image of Resilon upon access with size 15K file being inserted passively to working length (D) Resilon debris on a size 15K file

Case 3:

A 20-year-old Caucasian female with a penicillin allergy and no other contributory medical history presented to UNC-SOD. Tooth #3 was previously root canal treated 7 years prior. Clinically #3 presented with an acrylic provisional crown and FUJI build-up. The diagnosis was as follows: previously treated, symptomatic apical periodontitis.

Upon access, intact PermaFlo Purple composite orifice barriers were found covering four canals. Upon penetration of the orifice barriers, a potent smell was again noted that was significant enough for the patient to inquire about. The Resilon was discolored in all four canals, predominately dark gray (Fig 5C&D), The material was degraded in the mesial and palatal canals, however it was slightly more dense in the distal canal as determined by the 15 K file requiring some apical pressure to penetrate. As the file approached the middle third of the canal, the material became softer and an apical glide path was obtained passively. The retreatment rotary instrument augured the majority of the filling material from the coronal and middle thirds in segments (Fig. 5E). In the coronal of the distal canal, the material came out in more solid chunks than in the middle and apical third of the canal. Hedstroms were successful in removing the material in the apical third. When wiping the files on a piece of 4x4 gauze after inserting them into the canals, a dark gray residue was left behind similar to that which was smeared on the walls of the canals (Fig 5F). While the bulk of the filling material was removed, some of the smeared residue along the walls and in isthmuses/fins was left behind. Again, solvents were not used for removal as it seemed they would result in more smearing of the filling material. The remaining retreatment protocol was continued as described above. Following the initial visit, the patient did not experience a flare-up.

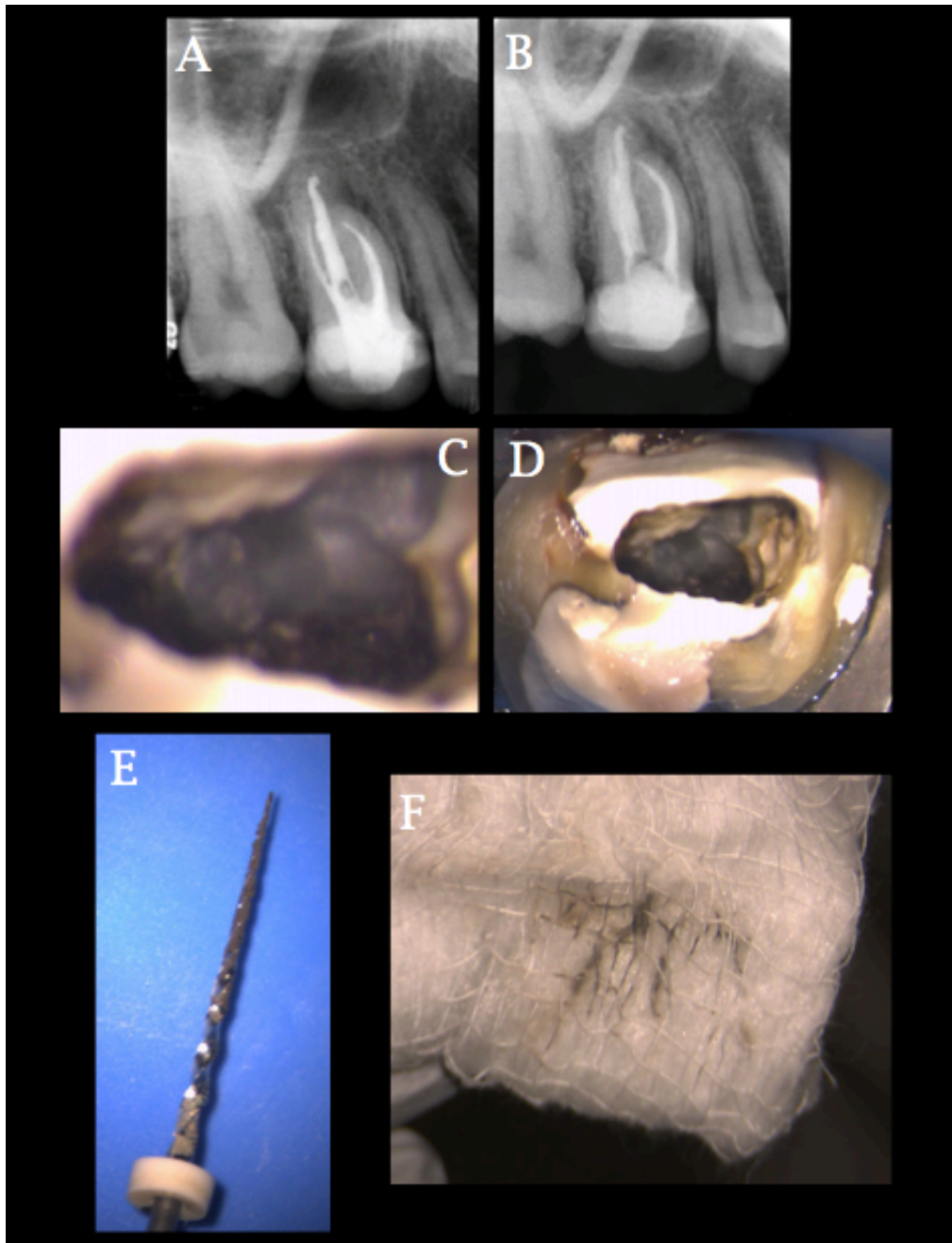


Figure 5: Radiographs and images from Case 3 (A) Pre-operative radiograph (B) Post- operative radiograph of retreatment (C) Image of degraded Resilon in canals upon access through intraorifice barriers (D) Image of degraded Resilon in canals upon access through intraorifice barriers (E) D3 Protaper Retreatment Rotary file with Resilon debris (F) 4x4 gauze after wiping Resilon debris off of a file

Discussion

In the present case series, non-healed cases obturated previously with Resilon/Epiphany were described in detail including the pattern of degradation, as well as descriptions of its removal and technical challenges, and the occurrence of flare-ups. While every retreatment is different, each with its own unique clinical challenges, these three cases are representative of the experience of retreating Resilon that has degraded.

One potential explanation for the degradation exhibited in these retreatments may be the inclusion of the biodegradable polyester polycaprolactone (PCL) in the Resilon formulation (6). PCL has traditionally been used as a component in drug- delivery devices due to its low melting point, biocompatibility, and susceptibility to biodegradation by enzymes and microorganisms (14). Hydrolases released by bacteria, yeast and fungi can result in the biodegradation of PCL through the cleavage of ester bonds (15). In a series of in vitro studies, the biodegradation of Resilon and PCL were demonstrated in the presence of abiotic factors such as alkaline hydrolases and biotic factors including endodontically relevant bacteria and fungi (5-7). Following exposure to dental sludge consisting of saliva, sputum, coagulated blood, plaque and calculus, enamel, dentin and shavings from restorative procedures, compression molded disks of Resilon and PCL both exhibited significant surface degradation compared to gutta percha (5). Emulsified Resilon was shown to degrade in the presence of cholesterol esterase, a component of salivary hydrolases and an inflammatory – cell derived enzyme (6). Monocyte-derived macrophages that secrete these enzymes have been shown to be present within periapical granulomas associated with endodontically infected teeth (16). This presents a possible explanation for the degradation noted in Case 1 and 3 in which a crown with clinically sound margins and intact

orifice barriers were found. In Case 3, the degradation of Resilon also appeared to progress towards the apical third of the distal canal and was more intact coronally. These findings contradict our initial prediction that orifice barriers and an adequate coronal seal would be protective against degradation and support the theory that the source of enzymatic degradation may be derived from the periapex.

The experience of retreating these Resilon cases was different than traditional gutta percha retreatments and hard paste retreatments. Establishing apical patency was done passively and removal of the filling material required no solvents or ultrasonic instrumentation. This differs from some of the reports in the literature describing the removal of pastes such as N2 or silver points which may require the use of ultrasonics and additional armamentarium and can be time-consuming (17-19). In a systematic review comparing gutta percha retreatment techniques, it was found that solvents enhanced file penetration but hindered canal cleanliness (20). Solvents were not used during these Resilon retreatments because file penetration to the apex was not a challenge due to its degraded consistency. When considering the time for and effectiveness of removal, our findings are consistent with previous reports in the literature that Resilon/ Epiphany can be removed quickly, however compared to gutta percha, leaves behind more residual material (21,22). In all of the cases in this series, a smear of Resilon was left covering portions of the canal walls.

The lack of flare-ups experienced by the patients in this series contradicts the literature, which reports a higher likelihood following retreatments (10,11). Gound et al. reported a higher than normal number of flare-ups following the retreatment of resorcinol-formaldehyde filled root canal retreatments (13). One explanation for the absence of flare-ups experienced in our case series is the lack of severe presenting symptoms. Many studies have identified pre-operative pain

and swelling as significant factors predisposing patients to flare-ups (9, 12). While the mechanisms of flare-ups are still not fully understood, evidence suggests that microbial factors play a significant role (23,24). It is possible that the environment created by the degraded Resilon may reduce the virulence of specific bacterial species involved in flare-ups.

The information and experience presented in this case series will hopefully aid practitioners in navigating the retreatment of a non-healed Resilon obturated root canals and allow them to provide the patient with appropriate expectations as to the potential for flare-ups. The degradation of Resilon into the paste-like material described in this case series facilitates sampling and analysis of the material in future studies to identify its chemical and microbiological content.

REFERENCES

1. Tay FR, Pashley DH. Monoblocks in Root Canals: A Hypothetical or a Tangible Goal. *J Endod.* 2007;33(4):391–8.
2. Shipper G, Orstavik D, Teixeira F, Trope M. An Evaluation of Microbial Leakage in Roots Filled with a Thermoplastic Synthetic Polymer-Based Root Canal Filling Material (Resilon). *J Endod.* 2004;30(5):342–7.
3. Teixeira FB, Teixeira ECN, Thompson JY, Trope M. Fracture resistance of roots endodontically treated with a new resin filling material. *J Am Dent Assoc [Internet]*. 2004;135(5):646–52.
4. Hammad M, Qualtrough A, Silikas N. Effect of New Obturating Materials on Vertical Root Fracture Resistance of Endodontically Treated Teeth. *J Endod.* 2007;33(6):732–6.
5. Tay F, Pashley DH, Loushine R, Kuttler S, Garcia-Godoy F, King N, et al. Susceptibility of a polycaprolactone-based root canal filling material to degradation. Evidence of biodegradation from a simulated field test. *Am J Dent.* 2007;20(6):265–369.
6. Hiraishi N, Sadek F, King N, Ferrari M, Pashley D, Tay F. Susceptability of a polycaprolactone- based root canal filling material to degradation using an agar-well diffusion assay. *Am J Dent.* 2008;21(2):119–23.
7. Tay F, Pashley D, Williams M, Raina R, Loushine R. Susceptibility of of a polycaprolactone- based root canal filling material to degradation. I. Alkaline hydrolysis. *J Endod.* 2005;31(8):593–8.
8. Barborka BJ, Woodmansey KF, Glickman GN, Schneiderman E, He J. Long-term Clinical Outcome of Teeth Obturated with Resilon. *J Endod.* 2017;43(4):556–60.
9. Walton R, Fouad A. Endodontic interappointment flare-Ups: A prospective study of incidence and related factors. *J Endod.* 1992;18(4):172–7.
10. Imura N, Zuolo M. Factors associated with endodontic flare-ups: a prospective study. *Int Endod J.* 1995;28:261–5.
11. Azim AA, Azim KA, Abbott P V. Prevalence of inter-appointment endodontic flare-ups and host-related factors. *Clin Oral Investig.* 2017;21(3):889–94.
12. Torabinejad M, Kettering JD, McGraw JC, Cummings RR, Dwyer TG, Tobias TS. Factors associated with endodontic interappointment emergencies of teeth with necrotic pulps. *J Endod.* 1988;14(5):261–6.

13. Gound TG, Marx D, Schwandt NA. Incidence of flare-ups and evaluation of quality after retreatment of resorcinol-formaldehyde resin ("Russian Red cement") endodontic therapy. *J Endod.* 2003;29(10):624–6.
14. Woodruff MA, Hutmacher DW. The return of a forgotten polymer - Polycaprolactone in the 21st century. *Prog Polym Sci.* 2010;35(10):1217–56.
15. Lefèvre C, Tidjani A, Vander Wauven C, David C. The interaction mechanism between microorganisms and substrate in the biodegradation of polycaprolactone. *J Appl Polym Sci.* 2002;83(6):1334–40.
16. Stern MH, Dreizen S, Mackler BF, Selbst AG, Levy BM. Quantitative analysis of cellular composition of human periapical granuloma. *J Endod* 1981;7:117–22.
17. Sieraski, S.M., Zillich, R.M. Silver point retreatment: review and case report. *J Endod.* 1983;9:35–39.
18. Suter, B. A new method for retrieving silver points and separated instruments from root canals. *J Endod.* 1998;24:446–448.
19. Krell KV, Neo J. The use of ultrasonic endodontic instrumentation in the retreatment of paste-filled endodontic teeth. *Oral Surg* 1985;60:100-2. 6.
20. Rossi-Fedele G, Ahmed HMA. Assessment of Root Canal Filling Removal Effectiveness Using Micro-computed Tomography: A Systematic Review. *J Endod.* 2017;43(4):520–6.
21. Ramzi H, Shokouhinejad N, Saghiri MA, Samieefard A. Efficacy and effectiveness of three different methods in the retreatment of root canals filled with Resilon/Epiphany SE. *Iran Endod J.* 2010;5(4):161-6.
22. Zarei M, Shahrami F, Vatanpour M. Comparison between gutta- percha and Resilon retreatment. *J Oral Sci.* 2009;51(2):181-5.
23. Siqueira J. Microbial causes of endodontic flare-ups. *Int Endod J.* 2003;36:453–63.
24. Seltzer S, Naidorf IJ. Flare-ups in endodontics: I. Etiological factors. *J Endod.* 2004;30(7):476–81.

THESIS SUMMARY

This thesis addresses the AAE research priority of the effect of obturation techniques on endodontic success. In part 1 of this study, the proportion of clinically degraded Resilon/ Epiphany in non-healed endodontic cases receiving retreatment was investigated. Previous in vitro studies provided hypotheses to the higher clinical failure rate of Resilon obturated root canals found in the Barborka et. al study including the susceptibility of Resilon and its components to degradation, however this was the first study to show clinical proof of this degradation (1-4). It was found that 78% of Resilon obturated canals were degraded compared to 0% of gutta percha obturated canals. Part 2 of this thesis, describes a series of cases in which non- healed Resilon obturated root canals were retreated. Detailed explanations of the pattern of degradation, as well as descriptions of its removal and technical challenges, and the occurrence of flare-ups were provided. In contrast to other studies that found a higher percentage of flare-ups among patients receiving retreatments of traditional gutta percha or paste fills, these Resilon retreatments did not result in flare-ups.

Findings from this clinical observational study have given us insight into the proportion of degradation of Resilon that occurs in non-healed cases and a potential explanation for Resilon's higher clinical failure rate. These clinical findings are significant when treatment planning non-healed Resilon filled teeth. The soft paste-like consistency of Resilon resulting in relatively simple removal during retreatment compared to gutta percha or hard paste fills, as well

as the lack of flare-ups following retreatment suggest a potential benefit of electing non- surgical retreatment over periapical microsurgery. Future studies could be done to determine the clinical success rate of retreated Resilon cases compared to traditional gutta percha retreatments. Further investigation should also be done to analyze the degraded Resilon material for its chemical and microbiological content, which may provide us with better understanding as to the potential impact on a patient's health.

REFERENCES

1. Tay F, Pashley DH, Loushine R, Kuttler S, Garcia-Godoy F, King N, et al. Susceptibility of a polycaprolactone-based root canal filling material to degradation. Evidence of biodegradation from a simulated field test. *Am J Dent.* 2007;20(6):265–369.
2. Hiraishi N, Sadek F, King N, Ferrari M, Pashley D, Tay F. Susceptability of a polycaprolactone- based root canal filling material to degradation using an agar-well diffusion assay. *Am J Dent.* 2008;21(2):119–23.
3. Tay F, Pashley D, Williams M, Raina R, Loushine R. Susceptibility of of a polycaprolactone- based root canal filling material to degradation. I. Alkaline hydrolysis. *J Endod.* 2005;31(8):593–8.
4. Barborka BJ, Woodmansey KF, Glickman GN, Schneiderman E, He J. Long-term Clinical Outcome of Teeth Obturated with Resilon. *J Endod.* 2017;43(4):556–60.

APPENDIX A: ADULT CONSENT FORM

University of North Carolina at Chapel Hill Consent to Participate in a Research Study Adult Participants

Consent Form Version Date: 09/12/2016

IRB Study # 16-1069

Title of Study: Long-term outcome assessment and treatment of Resilon obturation system compared to gutta percha.

Principal Investigator: Peter Tawil

Principal Investigator Department: Endodontics

Principal Investigator Phone number: 919-537-3403

Principal Investigator Email Address: pzt@unc.edu

Co-Investigators: Lesleigh Payne, Krista Andersen, Ceib Phillips, Ashraf Fouad

What are some general things you should know about research studies?

You are being asked to take part in a research study. To join the study is voluntary. You may refuse to join, or you may withdraw your consent to be in the study, for any reason, without penalty.

Research studies are designed to obtain new knowledge. This new information may help people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study.

You will be given a copy of this consent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

What is the purpose of this study?

The purpose of this study is to evaluate the long-term outcome of root canal therapy at the UNC graduate and predoctoral endodontic clinics. The materials used for treatment will be evaluated as well as other factors that could affect the success of treatment.

You are being asked to be in the study because you have had root canal therapy completed at UNC School of Dentistry at a time where different materials were in use.

Are there any reasons you should not be in this study?

You should not be in this study if you are under the age of 18.

How many people will take part in this study?

There will be approximately 1,000 people in this research study.

How long will your part in this study last?

Your participation in the research study will last as long as you are receiving follow-up care at the UNC School of Dentistry, which may range from one to four visits over a maximum of three months. Clinical information gathered during this time will be used for research purposes.

What will happen if you take part in the study?

The first visit will be your regular (standard of care) follow up evaluation and x-ray. You will not be charged for this visit.

If you are not having problems with your root canal and your dentist does not ask you to return for re-treatment, then your participation in the research study is complete and we will use your past dental records, as well as those from this visit, in our research study. These records include dental history, treatment notes, and x-rays.

If your dentist decides that you need re-treatment of your root canal, then the researchers will continue to use the clinical information from your re-treatment visits for the research. This re-treatment is not part of the research study and you will be responsible for the cost of re-treatment, which ranges from \$525.000 to \$750.00.

In addition, you will be given a 10-minute questionnaire to complete at home and return to the researchers at your last clinic visit. This questionnaire will ask you to record any post-operative pain or swelling that occurred, as well as any pain medicine taken for the first 72 hours after treatment. You may choose not to answer a question for any reason.

The dentist who treats you will be responsible for your welfare during the study.

What are the possible benefits from being in this study?

Research is designed to benefit society by gaining new knowledge. You will not benefit personally from being in this research study.

What are the possible risks or discomforts involved from being in this study?

There are no foreseen immediate or long-term physical, psychological, or social risks/discomforts from participating in the research.

There is a slight risk of a breach of confidentiality of your dental information. To prevent this, any information that we collect will not contain your name or any other identifying information. You will be assigned a research ID code. This code will be used on all of your data and on your questionnaire. In addition, all information will be kept on a password-protected computer or in a locked office, with only research personnel having access.

There may be uncommon or previously unknown risks. You should report any problems to the researcher.

What if we learn about new findings or information during the study?

You will be given any new information gained during the course of the study that might affect your willingness to continue your participation.

How will information about you be protected?

Every effort will be made to protect your privacy. All information collected in this study will remain confidential and only those directly involved in the study will have access to this information.

Participants will not be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies (for example, the FDA) for purposes such as quality control or safety.

What will happen if you are injured by this research?

All research involves a chance that something bad might happen to you. This may include the risk of personal injury. In spite of all safety measures, you might develop a reaction or injury from being in this study. If such problems occur, the researchers will help you get medical care, but any costs for the medical care will be billed to you and/or your insurance company. The University of North Carolina at Chapel Hill has not set aside funds to pay you for any such reactions or injuries, or for the related medical care. You do not give up any of your legal rights by signing this form.

What if you want to stop before your part in the study is complete?

You can withdraw from this study at any time, without penalty. The investigators also have the right to stop your participation at any time. This could be because you have had an unexpected reaction, or have failed to follow instructions, or because the entire study has been stopped.

Will you receive anything for being in this study?

You will not receive anything from being in this study.

Will it cost you anything to be in this study?

It will not cost you anything to be in this study.

What if you have questions about this study?

You have the right to ask, and have answered, any questions you may have about this research. If you have questions about the study (including payments), complaints, concerns, or if a research-related injury occurs, you should contact the researchers listed on the first page of this form.

What if you have questions about your rights as a research participant?

All research on human volunteers is reviewed by a committee that works to protect your rights and welfare. If you have questions or concerns about your rights as a research subject, or if you would like to obtain information or offer input, you may contact the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.

Participant's Agreement:

I have read the information provided above. I have asked all the questions I have at this time. I voluntarily agree to participate in this research study.

Signature of Research Participant

Date

Printed Name of Research Participant

Signature of Research Team Member Obtaining Consent

Date

Printed Name of Research Team Member Obtaining
Consent

APPENDIX B: HIPAA AUTHORIZATION

University of North Carolina at Chapel Hill

HIPAA Authorization for Use and Disclosure of Health Information for Research Purposes

IRB Study # 16-1069

Title of Study: Long-term outcome assessment and treatment of Resilon obturation system compared to Gutta Percha,

Principal Investigator: Peter Tawil

Mailing Address for UNC-Chapel Hill Department: CB:

This is a permission called a “HIPAA authorization.” It is required by the “Health Insurance Portability and Accountability Act of 1996” (known as “HIPAA”) in order for us to get information from your medical records or health insurance records to use in this research study.

1. If you sign this HIPAA authorization form, you are giving your permission for the following people or groups to give the researchers certain information about you (described below):

Any health care providers or health care professionals or health plans that have provided health services, treatment, or payment for you such as physicians, clinics, hospitals, home health agencies, diagnostics centers, laboratories, treatment or surgical centers, including but not limited to the UNC Health Care System and its members and affiliates (collectively, “UNCHCS”), health insurance plans, and government health agencies.

2. If you sign this form, this is the health information about you that the people or groups listed in #1 may give to the researchers to use in this research study:

Any information in your medical records that relates to your participation in this research. This information may include medical and dental health history, clinic notes, radiographs, and clinic visit schedule.

3. The HIPAA protections that apply to your medical records will not apply to your information when it is in the research study records. Your information in the research study records may also be shared with, used by or seen by collaborating researchers, the sponsor of the research study, the sponsor’s representatives, and certain employees of the University of North Carolina at Chapel Hill or other affiliated entities conducting the research, or government agencies (like the FDA) if needed to oversee the research study. HIPAA rules do not usually apply to those people or groups. If any of these people or groups reviews your research record, they may also need to review portions of your original medical record relevant to the situation. The informed consent document describes the procedures in this research study that will be used to protect your personal information. You can also ask the researchers any questions about what they will do with

your personal information and how they will protect your personal information in this research study.

4. If this research study creates medical information about you that will go into your medical record, you may not be able to see the research study information in your medical record until the entire research study is over.

5. If you want to participate in this research study, you must sign this HIPAA authorization form to allow the people or groups listed in #1 on this form to give access to the information about you that is listed in #2. If you do not want to sign this HIPAA authorization form, you cannot participate in this research study. However, not signing the authorization form will not change your right to treatment, payment, enrollment or eligibility for medical services outside of this research study.

6. This HIPAA authorization will not stop unless you stop it in writing.

7. You have the right to stop this HIPAA authorization at any time. You must do that in writing. You may give your written stop of this HIPAA authorization directly to Principal Investigator or researcher or you may mail it to the department mailing address listed at the top of this form, or you may give it to one of the researchers in this study and tell the researcher to send it to any person or group the researcher has given a copy of this HIPAA authorization. Stopping this HIPAA authorization will not stop information sharing that has already happened.

8. You will be given a copy of this signed HIPAA authorization.

Signature of Research Participant

Date

Printed Name of Research Participant

APPENDIX C: IRB APPROVAL LETTER

To: Peter Tawil
Endodontics

From: Biomedical IRB

Approval Date: 9/20/2016

Expiration Date of Approval: 9/19/2017

RE: Notice of IRB Approval by Expedited Review (under 45 CFR 46.110)

Submission Type: Initial

Expedited Category: 5.Existing or non-research data,7.Surveys/interviews/focus groups

Study #: 16-1069

Study Title: Long-term outcome assessment and treatment of Resilon obturation system compared to gutta percha.

This submission has been approved by the IRB for the period indicated. It has been determined that the risk involved in this research is no more than minimal.

Study Description:

Purposes: To assess the long-term outcome and treatment of Resilon/Epiphany filled root canals compared to gutta percha filled root canals

Participants: Patients from the University of North Carolina School of Dentistry who received root canal therapy (dental codes D3310, D3320, D3330, D3999, D3346, D3347, D3348) that was completed using Resilon/Epiphany obturation system or gutta percha from August 1, 2004 - August 31, 2013.

Procedures: Electronic patient records will be reviewed, the standard of care radiographs will be scored, and a written survey will be conducted of a subset of the participants.

Regulatory and other findings:

The IRB has determined that the study-specific rationale provided by the investigator is sufficient to justify a limited waiver of HIPAA authorization to identify potential subjects for recruitment into this research study, as allowed under 45 CFR 164.512. This temporary waiver provides access to protected health information (PHI) to confirm eligibility and facilitate initial contact, after which consent and HIPAA authorization will be sought when applicable. Access and use is limited to the minimum amount of PHI necessary to review eligibility criteria and to contact potential subjects.

Investigator's Responsibilities:

Federal regulations require that all research be reviewed at least annually. It is the Principal Investigator's responsibility to submit for renewal and obtain approval before the expiration date. You may not continue any research activity beyond the expiration date

without IRB approval. Failure to receive approval for continuation before the expiration date will result in automatic termination of the approval for this study on the expiration date.

Your approved consent forms and other documents are available online at http://apps.research.unc.edu/irb/index.cfm?event=home.dashboard.irbStudyManagement&irb_id=16-1069.

You are required to obtain IRB approval for any changes to any aspect of this study before they can be implemented. Any unanticipated problem involving risks to subjects or others (including adverse events reportable under UNC-Chapel Hill policy) should be reported to the IRB using the web portal at <http://irbis.unc.edu>.

Please be aware that additional approvals may still be required from other relevant authorities or "gatekeepers" (e.g., school principals, facility directors, custodians of records).

The current data security level determination is Level III. Any changes in the data security level need to be discussed with the relevant IT official. If data security level II and III, consult with your IT official to develop a data security plan. Data security is ultimately the responsibility of the Principal Investigator.

This study was reviewed in accordance with federal regulations governing human subjects research, including those found at 45 CFR 46 (Common Rule), 45 CFR 164 (HIPAA), 21 CFR 50 & 56 (FDA), and 40 CFR 26 (EPA), where applicable.