1-1-2012

Fluoride release, recharge, and re-release from four orthodontic bonding systems

Amy Bouvier
Nova Southeastern University

FLUORIDE RELEASE, RECHARGE, AND RE-RELEASE FROM FOUR ORTHODONTIC BONDING SYSTEMS

A Thesis Presented

By

AMY JOHANNA BOUVIER, D.M.D.

Submitted to the College of Dental Medicine of Nova Southeastern University

in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE IN DENTISTRY

December 2012

FLUORIDE RELEASE, RECHARGE, AND RE-RELEASE FROM FOUR ORTHODONTIC BONDING SYSTEMS

By

AMY JOHANNA BOUVIER, D.M.D.

A thesis submitted to the College of Dental Medicine of Nova Southeastern

University in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Orthodontics

College of Dental Medicine

Nova Southeastern University

December 2012

Approved as to style and content by:

APPROVED BY:

____

Cristina Garcia-Godoy, D.D.S., M.P.H. (Mentor) Date

APPROVED BY:

____

Abraham Lifshitz, D.D.S., M.S. (Committee Member) Date

APPROVED BY:

____

Jeffrey Thompson, Ph.D. (Committee Member) Date

APPROVED BY:

____

Shiva Khatami, D.D.S., Ph.D. (Committee Member) Date

APPROVED BY:

____

Robert A. Uchin, D.D.S. (Dean) Date

NOVA SOUTHEASTERN UNIVERSITY

Health Professions Division
Department of Orthodontics
College of Dental Medicine

STUDENT NAME: Amy Johanna Bouvier, D.M.D.

STUDENT E-MAIL ADDRESS: bouvier@nova.edu

STUDENT TELEPHONE NUMBER: (954) 854-7704

COURSE DESCRIPTION: Master of Science in Dentistry with specialization in Postgraduate Orthodontics

TITLE OF SUBMISSION: Fluoride Release, Recharge, and Re-release from Four Orthodontic Bonding Systems

DATE SUBMITED: November 1, 2012

I certify that I am the sole author of this thesis, and that any assistance I received in its preparation has been fully acknowledged and disclosed in the thesis. I have cited any sources from which I used ideas, data, or words, and labeled as quotations any directly quoted phrases or passages, as well as providing proper documentation and citations. This thesis was prepared by me, specifically for the M.Sc.D degree and for this assignment.

STUDENT
SIGNATURE:____
Amy Johanna Bouvier, D.M.D Date

Dedication

I would like to dedicate this thesis to my parents who have supported me, educated me, and most importantly, have loved me throughout all the years of my life. Without their encouragement and generosity, I would not be where I am today. Thank you, Mom and Dad!

Acknowledgements

I would like to acknowledge my mentor, Dr. Cristina Garcia-Godoy, who was instrumental throughout the entire process, from grant proposal to completion of the master's thesis. I would also like to acknowledge my committee members, Dr. Abraham Lifshitz, Dr. Jeffrey Thompson, and Dr. Shiva Khatami, who provided me with support, guidance, and assistance along the way. A very special thank you goes to Mr. Jim Rothrock, who aided me in conducting the scanning electron microscopy evaluation, instructed me in how to operate the laboratory equipment, and was a "hand model" for some materials and methods photographs. I would also like to thank those that helped with the statistical analysis, Dr. Patrick Hardigan, and Dr. Vinodh Bhoopathi.

Abstract

FLUORIDE RELEASE, RECHARGE, AND RE-RELEASE FROM FOUR ORTHODONTIC BONDING SYSTEMS

DEGREE DATE: DECEMBER 2012

AMY JOHANNA BOUVIER, D.M.D.,

COLLEGE OF DENTAL MEDICINE, NOVA SOUTHEASTERN UNIVERSITY

Thesis Directed By:

Cristina Garcia-Godoy, D.D.S., M.P.H., Mentor

Abraham Lifshitz, D.D.S., M.S., Committee Member

Jeffrey Thompson, Ph.D., Committee Member

Shiva Khatami, D.D.S., Ph.D., Committee Member

Objectives: To determine the amount of initial fluoride release from four orthodontic bonding systems over a period of four weeks, and then to subject these materials to an external source of fluoride for recharge in order to measure the amount of fluoride re-release over another four-week interval. Additionally the surface morphology of these materials was analyzed under the scanning electron microscope in order to identify microscopic changes in the materials that may have occurred during the experiment. **Methods:** Four orthodontic adhesives: Fuji Ortho LC (GC America, Alsip, IL), Transbond XT (3M Unitek, Monrovia, CA), Illuminate Light Cure (Ortho Organizers, Carlsbad, CA), and Opal Seal with Opal Bond MV (Ultradent, South Jordan, UT), n=120 (30/material) were

tested for fluoride release at 1 hour, 24 hours, 3 days, 1 week, 2 weeks, 3 weeks and 4 weeks. Samples (10/subgroup/material) were then recharged with an external source of fluoride (toothpaste, foam, or varnish), and retested for fluoride re-release at 1 hour, 24 hours, 3 days, 1 week, 2 weeks, 3 weeks and 4 weeks. The scanning electron microscope was utilized in order to assess each material's surface morphology before testing and after completion of the experiment (n=16). Descriptive statistics, means and standard deviations were calculated for all four materials and their subgroups at each time interval. A mixed model two-way ANOVA was run, using a level of significance of 0.05. Bonferroni multiple comparison tests were conducted using if groups were found to be statistically significantly different. To determine significant differences between fluoride release and re-release for each recharge subgroup within each material group, paired t-tests were performed for the time intervals of 24 hours, 2 weeks, and 4 weeks. For the paired t-tests, the level of significance used was 0.02 to allow for Bonferroni correction. **Results:** During the initial 24 hours the fluoride measurements (in mg/L or ppm) were as follows: Fuji 9.78±0.65, Illuminate 7.83±1.49, Opal 0.05±0.02, and Transbond 0.01±0.0. At the initial four weeks time point, the readings were as follows: Fuji 6.68±0.79, Illuminate 3.82±1.84, Opal 0.06±0.01, and Transbond 0.01±0.01. The greatest fluoride release came from the varnish subgroups from each of the materials at 2 weeks post re-charge: Fuji 9.16±1.53, Illuminate 7.5±3.1 (tied with foam subgroup 7.5±4.4), Opal 5.3±2.45, and Transbond 3.75±1.67. The greatest fluoride measurement for each material at the final week post-recharge was: Fuji varnish subgroup

8.3±3.58, Illuminate foam subgroup 6.5±3.5, Opal varnish subgroup 2.50±1.1, and Transbond varnish subgroup 1.72±1.82. SEM results showed an observable difference between the materials pre-experiment and post-experiment at a magnification of 50X and 500X. The Fuji foam and paste subgroups displayed surface crackling patterns at both magnifications when compared to the control and varnish samples. The Illuminate control, foam, and paste specimens all had a roughened grainy appearance, while the varnish specimen seemed to be smoothed over by the varnish material. The Transbond samples appeared to have observable differences in surface morphology at 50X, but not at 500X. The Opal paste and foam specimens appeared to have a smoother surface than both the control and the varnish samples. **Conclusions:** There were significant differences in release and re-release of fluoride among all four adhesives at different time intervals over a period of eight weeks. Significant increase in fluoride re-release was seen for all three of the recharge subgroups for both Opal and Transbond at each time interval. A significant increase in fluoride re-release for the Illuminate group was mainly observed at the end of second and fourth week. Though no significant increase in fluoride re-release was observed, Fuji released highest amount of fluoride during release and re-release, at all different time intervals. Fluoride varnish was the superior recharge material, as it provided the greatest fluoride measurements, followed by foam and toothpaste. There were observable changes in the surface morphology of the materials pre-experiment and post-experiment at a magnification of 50X and 500X, which may have an affect on the fluoride releasing capabilities of the materials.

Table of Contents

Acknowledgements vi

Abstract vii

Table of Contents x

List of Tables xii

List of Figures xiii

List of Appendices xiv

Chapter 1: Introduction 1

1.1 Overview 1

1.2 Fluoride Affects on Human Teeth 2

1.3 Types of Orthodontic Adhesive Materials 4

1.4 Fluoride Testing of Orthodontic Adhesive Materials 7

1.5 Purpose 9

1.6 Specific Aims and Hypotheses 9

1.6.1 Specific Aims 9

1.6.2 Hypotheses 10

1.7 Location of Study 10

Chapter 2: Materials and Methods 11

2.1 Sample Size 11

2.2 Sample Preparation 11

2.3 Fluoride Testing 12

2.4 Fluoride Recharge 13

2.5 Scanning Electron Microscopy 14

2.6 Statistical Analyses 14

Chapter 3: Results 16

Chapter 4: Discussion 21

Chapter 5: Conclusion 26

Bibliography 72

List of Tables

Table 1. Descriptive Statistics: Initial Fluoride Release…………………………..27

Table 2. Descriptive Statistics: Fluoride Re-release……………………………....28

Table 3. Mixed Model Statistics: Overall Initial Fluoride Release………………..29

Table 4. Mixed Model Statistics: Overall Fluoride Re-Release…………………..29

Table 5. Mixed Model Statistics: Subgroups Fluoride Re-Release……………...30

Table 6. Paired T-tests Pre vs. Post Recharge at 24 Hours...............................32

Table 7. Paired T-tests Pre vs. Post Recharge at 2 Weeks……………………...33

Table 8. Paired T-tests Pre vs. Post Recharge at 4 weeks…………………......34

Table 9. Pre vs. Post Recharge Differences between Groups at 24 Hours…….35
.
Table 10. Pre vs. Post Recharge Differences between Groups at 2 Weeks…...37

Table 11. Pre vs. Post Recharge Differences between Groups at 4 Weeks…...39

List of Figures

Figure 1. Sample Flow Chart for each of the Materials……………………………..41

Figure 2. Orthodontic Bonding Materials………………………………………..42

Figure 3. Sample Preparation……………………………………………………42

Figure 4. Samples in Capped Plastic Containers….……………………………...43

Figure 5. Incubator…………………………………………………………………43

Figure 6. Fluoride Meter…………………………………………………………….. 44

Figure 7. Rinse and Blot Dry………………………………………………………44

Figure 8. TISAB II…………………………………………………………………..45

Figure 9. Recharge Materials……………………………………………………..45

Figure 10. Scanning Electron Microscope………………………………………46

Figure 11. Graph of Fluoride Release: Initial Four Weeks………………………47

Figure 12. Graph of Fluoride Re-release: Fuji……………………………………..48

Figure 13. Graph of Fluoride Re-release: Illuminate……………………………49

Figure 14. Graph of Fluoride Re-release: Transbond……………………………50

Figure 15. Graph of Fluoride Re-release: Opal……………………………………51

Figure 16. Graph of Overall Fluoride Release and Re-release…………………52

Figure 17. SEM Images at 50X……………………………………………………...53

Figure 18. SEM Images at 500X……………………………………………………54

List of Appendices

Appendix A. A Priori Power Analysis for Determination of Sample Size……….55

Appendix B. Raw Data Fluoride Release…….……………………………………….56

Appendix C. Raw Data SEM Images……………………………………………......66

Chapter 1: Introduction

1.1 Overview

Appearance of enamel white spot lesions, or enamel decalcifications, are the beginning stages of caries formation and are considered to be the most important iatrogenic effect of fixed orthodontic appliance therapy.[1] Studies have discovered that approximately half of orthodontic patients may show an increase in enamel decalcification, in the absence of fluoride, within the first four weeks of orthodontic therapy.[2-9] The presence of orthodontic brackets and wires increases plaque retention and makes oral hygiene more difficult, thus explaining the increased incidence of caries in orthodontic patients.[2] Fluoride can prevent and sometimes even help reverse caries formation and progression by reacting with the enamel surface to form calcium fluoride and fluorapatite, making the surface more resistant to demineralization and decay.[10] If a fluoride releasing material was routinely used for orthodontic bracket bonding, the incidence of white spot lesions might dramatically decrease.[11]

Some orthodontic supply manufacturers have created adhesives that contain fluoride with claims that after the fluoride has been released from the material it can be recharged with by an external source of fluoride.[12-14] Once the material is recharged it is theoretically able to release fluoride over time again and again. These products would be ideal for preventing enamel demineralization around fixed orthodontic appliances. Therefore, it is important to determine what are the amounts of fluoride that are released from these products over time, and what is the fluoride recharge-ability of the materials.[12]

1.2 Fluoride Affects on Human Teeth

In the early 1900's Dr. Frederick McKay and Dr. G.V Black studied the condition of brown stained teeth among a population in Colorado, and termed it as mottled enamel.[15, 16] It was discovered that mottled enamel was very resistant to dental decay. Then in the 1930's it was discovered that the water in the area where this population lived had high levels of naturally occurring fluoride which was causing this mottled enamel to form.[16] These discoveries led to the fluoridation of public water supplies in optimal amounts which has dramatically improved the oral health of the public at large.[17]

In the United States, the optimal range of fluoride in drinking water has been established at 0.7 to 1.2 parts per million (ppm), or milligrams/L (mg/L). This is a lower concentration than would cause fluorosis or "mottled enamel" to form during the development of the dentition, yet a concentration that will still have the benefit in making the teeth resistant to caries formation.[18] The tolerable upper limit intake level (UL) is the estimated maximum level of intake that should not cause unwanted effects on health. The UL for fluoride is 0.1 mg/kg/day for individuals younger than eight years old. Adults and children over the age of eight are no longer at risk of dental fluorosis, and therefore the UL for them is 10 mg/day regardless of weight.[19]

Ingested fluoride from water, food, or supplements becomes systemic fluoride. Systemic fluoride can be incorporated into tooth structure while the dentition is developing. Fluoride deposited into pre-erupted teeth provides long lasting protection from caries formation after eruption into the oral cavity. Once the teeth are already developed and erupted, systemic fluoride present in saliva can serve as topical fluoride and be incorporated into the tooth's surface to prevent caries formation.[20] Other sources of topical fluoride include toothpastes, mouth rinses, foams, gels, and varnishes. Topical fluoride can help prevent and reverse the process of dental decay.[21]

Dental enamel is composed of hydroxyapatite. Fluoride reacts with the enamel's hydroxyapatite to form fluorapatite. Fluorapatite is less soluble than hydroxyapatite, which makes the tooth more resistant to caries formation.[22] White spot lesions are decalcifications that occur below the enamel surface as a result of acid attack from dental plaque. As long as there is an intact surface of enamel, these lesions can be remineralized with good oral hygiene, adequate salivary flow, and topical fluoride treatments.[23]

In 2007, study from Yamazaki, Litman, and Margolis showed the effect of fluoride on artificial caries lesion progression and repair on human enamel. Their research found that fluoride concentrations greater than or equal to 0.19 ppm were preventative of demineralization on sound enamel. Intermediate fluoride concentrations of 2.1-10.1 ppm would allow remineralization of the outer portion of an existing artificial caries lesion while simultaneously allowing demineralization of the inner portion of the lesion. Notably higher concentrations, 25 ppm, were required to prevent further demineralization of existing artificial caries lesions. They concluded that fluoride effects on enamel not only depend on the concentration of fluoride but also the caries status of the enamel as well.[24]

1.3 Types of Orthodontic Adhesive Materials

In the 1980s, bonding of orthodontic attachments became a routine clinical procedure, which eliminated the necessity of banding each tooth. Successful orthodontic bonding depends on three elements: 1. the prepared tooth surface, 2. the mesh design of the attachment base, and 3. the bonding material, or adhesive itself.[25] This study will focus specifically on the third element, the bonding materials.

The types of bonding materials used in orthodontics include dental cements, glass ionomers, resins, resin-modified glass ionomers, and polyacid-modified composite resins. Each of these materials differ in their physical and chemical characteristics. These differences are what influences each materials clinical applications and utility.[26]

Dental cements are composed of an acid and a base component, which when combined results in a neutralization reaction that sets and hardens the mixture.[27] Zinc-phosphate cement has been used in dentistry for more than a century due to its desirable physical properties of being dimensionally stable with low solubility in saliva. However, it is not very useful in the bonding of orthodontic attachments because of its inability of bonding to enamel or metal.[28] In contrast, polycarboxylate cements are able to chelate calcium in enamel and dentin, which results in a chemical bond to the tooth surface. The carboxyl groups are also able to bond with other metal surface oxides as well. Unfortunately these cements are highly soluble and have low fracture resistance, which limits its clinical usefulness in orthodontics as well.[29]

Glass ionomers contain carboxyl groups that chelate to enamel, dentin, and most metals through a reaction involving polyalkenoic acids with aluminosilicate glass. Fluoride ions are released when the alkaline composition of the material reacts with acids during and after setting of the material. Glass ionomer cements also go through hydrogel phases that support the movement of calcium and other ions associated with remineralization of enamel. The hydrogel phase is likely responsible for the uptake and re-release of fluoride from topical fluoride applications. Glass ionomers have better bond strength than the polycarboxylate cements.[30, 31] Capsulation of the glass ionomers allows preparation of the material in a triturator, which helps to eliminate errors involved with hand mixing.[32, 33] Although the literature reports low bracket retention rates for glass ionomers, they do provide chemical adhesion to tooth structure in moist environments without the requirement of acid etching or drying.[26]

Resin-modified glass ionomer cements are glass ionomer cements with the addition of 10-20% resin monomers that can be initially hardened through light curing or by chemical activation of the polymerization of the monomers. They have improved physical properties and more stable hydrogel phases than traditional glass ionomer cements, which makes them more useful in orthodontics.[31, 34] This type of adhesive also bonds to enamel through micromechanical retention of the resin tags in addition to the chemical bond through chelation from the acid-base reaction. Since the materials are dual cured, both light cured and chemically cured, there is improved early fracture resistance, maturation hardening, and sustained fluoride release and recharge.

They also have the ability to adhere to the tooth surface in a damp environment.[35, 36]

Resin adhesives are composed of fillers and resin monomers.[27] They can be either light cured, chemically cured, or dual cured.[37] To eliminate technique sensitivity with mixing of the adhesive, the single component light activated resin adhesives are preferred. Since polymerization is the only setting reaction, these materials do not form hydrogels, do not contain water, and do not release significant amounts of fluoride.[26] Enamel must be prepared through acid etching techniques in a dry field in order for resin adhesives to adhere through micromechanical bonding.[37, 38] Resin adhesives are less brittle, resist fracture better than cements, and reach their optimal physical properties rapidly with light activation.[26]

Compomers are polyacid–modified composite resins, which were developed to add fluoride-releasing properties to resin adhesives for caries inhibition. These adhesives are also light cured, but in theory a delayed acid-base reaction occurs after water sorbs into the compomer, which would allow release of fluoride from the aluminosilicate glass.[39] Hydrogel phases do not form, but fluoride recharging and re-release may occur through sorption and diffusion.[40-44] Like resin adhesives, compomers require acid etching and a dry field for adhesion to tooth structure to occur. They have improved strength compared to resin-modified glass ionomers, but resin adhesives have superior bond strength.[42, 45]

1.4 Fluoride Testing of Orthodontic Adhesive Materials

A study by Ahn et. al tested different types of orthodontic adhesives for fluoride release, then subjected the samples to topical fluoride and retested them for fluoride reuptake and re-release. This study showed that fluoride releasing adhesives can serve as a reservoir for topical fluoride, and that the resin modified glass-ionomer releases the highest amount of fluoride ions when recharged. Surprisingly, the study also showed that the non-fluoride containing composite that was tested as a control was also able to uptake and release small amounts of fluoride after topical fluoride application. The authors deduced that this might be due to pores and cracks within the composite that the fluoride was able to diffuse into. In their study, they determined that the theoretical level of fluoride release to inhibit white spot lesion formation in the vicinity of orthodontic appliances to be 2.68-5.37 ppm/g/day. The resin modified glass ionomers were the only adhesives that were able to release fluoride at a rate over this critical level. The overall conclusion drawn from this research was that resin modified glass ionomer in combination with a fluoride-containing mouthwash is the most effective protocol for long-term fluoride re-release.[12]

A similar study by dos Santos et. al. found that the materials released their peak fluoride release within 24 hours after the initial setting, which was a greater amount than what was measured at the initial one hour reading. Overall, fluoride release values were higher during the first week of testing, and then tapered off to low levels during the following three weeks. This study also showed that the resin modified glass ionomers had a higher capacity for capturing and releasing fluoride compared to the other materials studied.[13]

Markovic, Petrovic, and Peric conducted a laboratory study to determine the fluoride concentrations at the surface of glass ionomer materials with respect to different storage media and different pH environments. They also looked at the recharge-ability of the materials after submersion in a sodium fluoride solution, and assessed the morphological changes at the material surface using scanning electron microscopy and energy dispersive spectroscopic techniques. The results of the study showed that the highest fluoride content is at the surface of the material, and the materials have the ability to extensively reabsorb fluoride ions, especially in acidic environments.[46] Likewise, Delbem et. al. also found that fluoride release and recharge was greater for restorative materials treated with an acidulated phosphate fluoride gel compared to the same materials treated with a neutral (pH) fluoride gel.[47]

A study conducted by Gandolfi et. al. on fluoride release and absorption at different pH from glass ionomer cements concluded that fluoride release may depend on the surface degradation caused by the pH in the solution. Massive superficial breakage of the materials was seen under scanning electron microscopy, which probably promoted the releasing processes.[48] Another study using glass ionomer cements and resin-based fissure sealants showed that after exposure to acidulated fluoride gel, the surface roughness of the materials increased and the compressive strength decreased over time. It was concluded that although the materials showed rechargeable fluoride releasing capabilities, the mechanical properties of the materials became inferior.[49]

1.5 Purpose

Based on the literature reviewed above, it is important that new materials are created that will have a high capacity for fluoride release, recharge, and re-release, and also maintain clinically acceptable mechanical properties. The purpose of this study was to determine the fluoride release, recharge, and re-release from four orthodontic adhesives. The materials that were tested are: a standard resin modified glass ionomer that has been commonly tested, a composite resin adhesive that has also been commonly tested, a new resin modified glass ionomer, and a new composite resin adhesive which is used in conjunction with a 38% filled primer containing glass ionomer and nano-fillers. The materials were also observed under scanning electron microscopy before and after the experimentation in order to determine any changes that occurred to the surface morphology that could affect the fluoride releasing properties of the adhesives.

1.6 Specific Aims and Hypotheses

1.6.1 Specific Aims

I. To determine the initial amount of fluoride release from four orthodontic bonding materials over four weeks at specified time intervals.

II. To determine the amount of fluoride recharge and re-release from four orthodontic bonding materials over four weeks, after the materials have been subjected to an external source of fluoride for recharge over the same specified time intervals.

III. To examine the surface morphology of the materials before and after experimentation in order to determine any changes that may have occurred.

1.6.2 Hypotheses

I. Ho: If initial fluoride release is measured from four orthodontic bonding materials over four weeks, there will be no differences among the materials' measurements.

II. Ho: If an external source of fluoride is used to recharge the four orthodontic bonding materials and then the materials are measured for fluoride re-release over four weeks, there will be no differences among the materials' measurements

III. Ho: If four orthodontic bonding materials are examined under scanning electron microscope before and after the experimentation, there will be no changes observed between the two time points.

1.7 Location of Study

The design, preparation, data collection, and analyses for this study took place at:

Bioscience Research Center

Nova Southeastern University

College of Dental Medicine

3200 South University Drive

Fort Lauderdale, FL 33328

Chapter 2: Materials and Methods

2.1 Sample Size

Sample size was calculated by conducting a priori power analysis (see Appendix A) using data from the work of de Santos et. al.[13] It was determined that a sample size of 124 (31 specimens of each of the four orthodontic adhesive material) was necessary for the study. This included the 112 total specimens (28 per group) determined by the priori power analysis, an additional 2 specimens per group added to take into account error in specimen fabrication, and one additional sample of each of the four materials to be fabricated for baseline SEM analysis (See Figure 1). A specimen was taken from each subgroup (total of 12) post-experiment for SEM analysis, and was compared with the initial baseline SEM specimens (total of 4).

2.2 Sample Preparation

The materials tested in this study were: Illuminate Light Cure (Ortho Organizers, Carlsbad, CA), a resin-reinforced glass ionomer, Fuji Ortho LC (GC America, Alsip, IL), a resin-reinforced glass ionomer, Opal Seal with Opal Bond MV (Ultradent, South Jordan, UT), a 38% filled primer (glass ionomer with nano-fillers) used in conjunction with companion composite adhesive, and Transbond XT (3M Unitek, Monrovia, CA) a non-fluoride containing composite adhesive used as a control. (See Figure 2.)

All test specimens were fabricated at room temperature using a preformed Teflon mold (1.5 x 9.2mm). The Teflon mold was placed over a mylar strip that had been placed over a glass slab and then filled with the material. Each material was prepared according to manufacturers' instructions. Special instructions for sample preparation were necessary for both the Fuji Ortho LC and the Opal groups. The Fuji Ortho LC capsules required trituration for 10 seconds in an amalgamator (GC Coe Mix 5000, Alsip, IL) prior to dispensing of the material into the Teflon mold. For the Opal group, the bottom mylar strip was considered to be "prepared enamel", and the Opal Seal was therefore placed first onto the bottom mylar strip, air thinned for 2 seconds, and then the Opal Bond MV was placed on top of that. After the Teflon mold had been filled with the orthodontic bonding material, the top surface was then covered with another mylar strip and gently pressed using a second glass slab. Gentle hand pressure was used on the glass slab in order to facilitate removal of excess material and ensure a flat surface. The materials were then light cured (Optilux 501, Kerr Dental, Orange, CA) at 600 mW/cm^2 for 40 seconds each. (See Figure 3.) In order to prevent cross-contamination, the Teflon mold and glass slabs were cleaned of material debris between specimen fabrication using 70% isopropyl alcohol and a gauze. Additionally, a fresh new mylar strip was used for each sample. The specimens were all weighed in order to ensure consistent specimen size.

2.3 Fluoride Testing

The specimens were placed in 10 ml of deionized water in a capped plastic container (Figure 4) and stored in a 37 degree Celsius incubator (Figure 5) until each time interval was reached. The 10 milliliter (ml) volumes were analyzed for fluoride ion (F-) content using a calibrated fluoride meter (Thermo Scientific Orion 4 star pH/ISE, Waltham, MA) at 25 degrees Celsius (Figure 6).

The specimens were then rinsed with deionized water and blotted dry (Figure 7) before placement into 10 ml of fresh deionized water and stored at 37 degrees Celsius until the next time interval for F- measurement. Control volumes of deionized water (incubated without specimen) were analyzed at each time point as well. For testing, a buffer solution TISAB II (Thermo Scientific, Waltham, MA) was used in a 1:1 ratio as a decomplexing agent in both calibration samples as well as experimental samples. (See Figure 8.) The testing interval was as follows: 1 hour, 24 hours, 3 days, 1 week, 2 weeks, 3 weeks, 4 weeks.

2.4 Fluoride Recharge

After testing on the 28th day, the specimens were rinsed with deionized water and blotted dry. Then, the 30 specimens from each group were randomly divided into three groups of 10. Each group of 10 was then randomly selected to receive fluoride recharging from one of three conventional sources of fluoride: acidulated fluoride phosphate foam containing 1.23% w/v fluoride ion for 1 minute (Oral B Minute-Foam, Procter & Gamble, Cincinnati, OH), 0.24% sodium fluoride dentifrice slurry containing 0.14% w/v fluoride ion immersing the sample for 2 minutes (1:1 deionized water to Crest Cavity Prevention Toothpaste, Procter & Gamble, Cincinnati OH) or a single application of a 5% sodium fluoride varnish (Cavity Shield, 3M ESPE, St. Paul, MN). (See Figure 9.) The samples were then rinsed with deionized water, blotted dry, and then placed into vials with 10 ml of fresh deionized water. Fluoride testing was then carried out over the same intervals over a four-week period of time as it was done previously.

2.5 Scanning Electron Microscopy

An extra sample of each material (total of 4 specimens), as previously described, was analyzed under SEM (Quanta 200- FEI, Hillsboro, OR) to assess the baseline surface morphology (See Figure 10). After completion of the study, one sample from each of the recharged groups (total of 12 specimens) was randomly selected to be analyzed under SEM. Each SEM specimen was placed in the argon gas-pressurized sputtering chamber of the sputter coater machine (Cressington 108 Auto Sputter Coater, Watford, UK) and covered in a layer of gold in order to be visualized under the SEM. Each specimen was imaged at both 50X and 500X magnifications. Descriptive comparisons were made as to whether any changes occurred to the surface morphology of the materials during the experiment.

2.6 Statistical Analyses

All data collected for F- release was recorded on an Excel spreadsheet. Descriptive statistics, means, and standard deviations were calculated for all four materials and their subgroups at each time interval. To test the hypothesis, a mixed model two-way ANOVA was run, using a level of significance of 0.05. For the first half of the experiment the fixed effects were the different materials and time. The interaction was the type of material x time. For the second half of the experiment the fixed effects were the material, source of fluoride recharge, and time. The interaction was material x source of fluoride recharge x time. Bonferroni multiple comparison tests were conducted using if groups were found to be statistically significantly different. To determine significant differences between fluoride release and re-release for each subgroup within each material, paired t-tests were performed for the time intervals of 24 hours, 2 weeks, and 4 weeks. For the paired t-tests, the level of significance used was 0.02 to allow for Bonferroni correction.

Chapter 3: Results

During the initial 24 hours the fluoride measurements (in mg/L or ppm) were as follows: Fuji 9.78±0.65, Illuminate 7.83±1.49, Opal 0.05±0.02, Transbond 0.01±0.0. At the initial four weeks time point, the readings were as follows: Fuji 6.68±0.79, Illuminate 3.82±1.84, Opal 0.06±0.01, and Transbond 0.01±0.01. The greatest fluoride release came from the varnish subgroups from each of the materials at 2 weeks post re-charge: Fuji 9.16±1.53, Illuminate 7.5±3.1 (tied with foam subgroup 7.5±4.4), Opal 5.3±2.45, and Transbond 3.75±1.67. The greatest fluoride measurements for each material at the final week post-recharge were: Fuji varnish subgroup 8.3±3.58, Illuminate foam subgroup 6.5±3.5, Opal varnish subgroup 2.50±1.1, and Transbond varnish subgroup 1.72±1.82. SEM results showed an observable difference between the materials pre-experiment and post-experiment at a magnification of 50X and 500X.

Descriptive statistics for the initial fluoride release over the first four weeks is listed in Table 1. Descriptive statistics for the fluoride re-release after recharge, over the second four weeks, is listed in Table 2. Mixed model two-way ANOVA statistics for overall initial fluoride release over the first four weeks is listed in Table 3. Mixed model two-way ANOVA statistics for overall fluoride re-release after recharge, over the second four weeks, is listed in Table 4. Mixed model two-way ANOVA statistics showing overall differences between subgroups of each material for fluoride re-release after recharge, over the second four weeks, is listed in Table 5. Paired t-test statistics of pre vs. post recharge within groups at 24 hours, 2 weeks, and 4 week are listed in Table 6, Table 7, and Table 8, respectively. Mixed model two-way ANOVA statistics of pre vs. post recharge between groups at 24 hours, 2 weeks, and 4 weeks are listed in Table 9, Table 10, and Table 11 respectively.

A graphical representation of initial fluoride release for all four of the materials, over the first four weeks, is depicted in Figure 11. A graph of fluoride re-release after recharge showing each subgroup for the material Fuji, over the second four weeks, is depicted in Figure 12. A graph of fluoride re-release after recharge showing each subgroup for the material Illuminate, over the second four weeks, is depicted in Figure 13. A graph of fluoride re-release after recharge showing each subgroup for the material Transbond, over the second four weeks, is depicted in Figure 14. A graph of fluoride re-release after recharge showing each subgroup for the material Opal, over the second four weeks, is depicted in Figure 15. A graph of overall fluoride release and re-release over the entire eight week period is depicted in Figure 16.

Figure 11 illustrates that during the initial four weeks of the experiment, the Fuji and Illuminate groups released a significant amount of fluoride, while the Transbond and Opal groups were similar to the control of deionized water. The peak release of fluoride for Fuji and Illuminate were each at 24 hours. Fuji experienced a second peak at 1 week and also at 2 weeks, while Illuminate experienced one other peak at 2 weeks. As seen in Table 3, the initial fluoride release from Fuji was significantly more than that of Illuminate, and the fluoride release from both Fuji and Illuminate was significantly greater than that of the other groups.

During the second four weeks of the experiment, as seen in Figures 5, 6, 7, and 8, the recharge subgroups of varnish released the most fluoride, followed by the recharge subgroups of foam, and then the recharge subgroups of paste. Table 4 shows that during the second four weeks of the experiment Fuji and Illuminate were not statistically different from each other, and neither were Opal compared to Transbond.

In Table 6, the paired t-tests at 24 hours show that the foam and paste subgroups for Illuminate decreased the fluoride re-release significantly while the varnish group did not change the fluoride re-release significantly. Also at 24 hours, the foam and varnish subgroups significantly increased the fluoride re-release for Opal, while the paste subgroup was no different than the initial release. All three recharge subgroups significantly increased the fluoride re-release for Transbond at 24 hours post-recharge. Conversely, all three recharge subgroups significantly decreased fluoride re-release for Fuji at 24 hours post-recharge.

Table 7 shows that at 2 weeks, the significant differences between pre- and post- recharge within materials were seen in all subgroups for all materials except for the paste and varnish groups for Illuminate, and the varnish group for Fuji. Of the significant differences that were found, increases in fluoride re-release was the commonality, except for the Fuji subgroups, which experienced significant decreases in fluoride re-release for the foam and paste subgroups.

Significant increases in fluoride re-release at 4 weeks, shown in Table 8, were seen in all subgroups except for Illuminate varnish (no significant difference), Opal foam (no significant difference), and Fuji varnish (no significant difference). The foam and paste subgroups for Fuji showed a significant decrease in fluoride re-release at 4 weeks as well.

Scanning electron microscopy images are depicted in Figure 17 at 50X magnification, Figure 18 at 500X magnification, and raw data SEM images, which are slightly clearer, are located in Appendix C. Significant differences in surface morphology at 50X magnification were noted between the control specimen of Fuji compared to the all three Fuji subgroup specimens, the control specimen of Transbond with the Transbond varnish subgroup specimen, and the control specimen of Opal with all three the Opal subgroup specimens. Significant differences in surface morphology at 500X magnification were noted between the control specimen of Fuji with all three of the Fuji subgroup specimens, the control group of Illuminate with the Illuminate varnish subgroup specimen, and the control specimen of Opal with all three of the Opal subgroup specimens.

The Fuji foam and paste subgroups displayed surface crackling patterns at both magnifications when compared to the control and varnish samples. The Illuminate control, foam, and paste specimens all had a roughened grainy appearance, while the varnish specimen seemed to be smoothed over by the varnish material. The Transbond samples appeared to have observable differences in surface morphology at 50X, but not at 500X. The Opal paste and foam specimens appeared to have a smoother surface than both the control and the varnish samples.

Chapter 4: Discussion

As would be expected of resin-modified glass ionomers, Fuji and Illuminate both released significant amounts of fluoride ions throughout the study. In accordance with what was described by dos Santos et. al., during the first portion of the study, the peak fluoride release from the resin-modified glass ionomers were recorded at 24 hours, which was greater than the first hour reading.[13] Although the Opal product was used in conjunction with the Opal Seal (which is advertised to release fluoride, recharge, and re-release fluoride) it did not release fluoride in clinically significant amounts during the first four weeks of the study. This is most likely due to the fact that the source of fluoride is contained within such a thin layer of a 38% filled primer (Opal Seal), that the amount of fluoride to be released is negligible. Transbond performed very similarly to Opal. Both of these resin composite adhesives were very similar to the control of deionized water during the first four weeks of the study.

In the second half of the experiment, it was seen that the recharging of the materials with varnish provided the most fluoride re-release overall, followed by foam, and then paste. During the second four weeks of the experiment Fuji and Illuminate were not statistically different from each other, and neither were Opal compared to Transbond. Yet all the materials experienced significant differences between the first portion of the experiment compared to the second portion. Fuji was the only material that actually decreased the amount of fluoride release after recharge. This is possibly due to the fact that this material had not yet fully released its innate source of fluoride, and the recharge materials placed over the surface may have had a lesser quantity of fluoride than the material itself. It is also likely that had the Fuji not been re-charged during the second four weeks, the fluoride release would have tapered off to lower levels, at which point the recharge materials would have been able to increase the amount of fluoride re-release. The control of water was not compared in the second half of the statistical set, as there was no recharging protocol performed on the control of deionized water, and therefore there were no re-release values for comparison. However, as seen in Figure 16, deionized water continued to stay at the baseline of zero fluoride release throughout the entire eight weeks.

The differences in fluoride release found between the three different recharge materials may be explained by the fact that the materials contained different concentrations of fluoride, different modes of application, and different adherences to the materials. The foam subgroup released the greatest fluoride concentration for the first hour reading for three out of four of the materials (Fuji, Illuminate, Opal), but significantly decreased at the 24 hour reading. This is likely due to the fact that the fluoride content of the foam was very high, but the solubility of the acidulated fluoride foam allowed it to be rinsed away after the first few readings, as in the case of Opal and Transbond. The increase in release from the foam subgroups from the resin modified glass ionomers, Fuji and Illuminate, after the 24 hour readings may be due to the recharging and fluoride releasing properties inherent to this type of material. The varnish subgroups released the most fluoride overall. This is likely due to the tacky consistency of the varnish that allowed it to adhere well to the surfaces of the samples throughout time. The toothpaste subgroups released the least amount, as the slurry contained the least amount of fluoride and it was easily washed away from the surfaces of the samples.

Generally, more differences in surface morphology were noted in the SEM images at the higher magnification (500X). However it is interesting to note that differences were seen at 50X for the Transbond control versus the Transbond varnish subgroup, but were not seen for any of the Transbond specimens at the higher magnification of 500X. Micro-crackling of the surface was seen in both the Fuji foam and Fuji paste subgroups as compared to the control at both magnifications. This pattern was not seen in any other group, which may indicate specific interaction between the Fuji material with these two different recharging materials. Although the Fuji group did not re-release more fluoride in the second portion of this study, these micro cracks may be sights of fluoride uptake for later release as described in the literature by Ahn et al.[12] In contrast, it is also likely that these micro-cracks might have been caused by the vacuum and sputter coating process involved with SEM imaging. This process desiccates the samples, and therefore these cracks may likely be remnants of the area where the water was removed from the materials.

The Illuminate control, foam and paste specimens were all depicted with a roughened, grainy appearance. The Illuminate varnish specimen differed from the others, as the varnish seemed to be covering most of the projections, smoothing the surface out quite a bit. The study by Gandolfi et. al. reported similar superficial breakage of the surface topography of the materials, and postulated that this most likely promotes the ion releasing process.[48] The paste and foam specimens of Opal seemed to have a smoother surface morphology compared to the control, whereas the varnish subgroup appeared to have areas that were smooth combined with some scattered projections. Since the Opal group had two different surfaces, it is very possible that the imaged smooth surfaces could be the sealed side, while the more roughened images were the medium viscosity adhesive surface or visa versa.

Some limitations of this study include the fact that it is an *in vitro* laboratory experiment, which may not directly correlate with clinical settings, or *in vivo*. The amount of fluoride release is directly related to the amount of material tested. The size of the experimental discs may or may not be similar to the amount of material exposed to ion release in the mouth. A future study could use bonded brackets with the materials to test how much fluoride is released from a single tooth, single arch, or whole mouth. Also, the literature tells us that the pH of the environmental solution and the materials affects the fluoride release and recharging potential.[22, 46] However the pH was not measured in this study, as the focus was to determine fluoride release only. Even though differences in surface morphology were seen in pre and post experimental SEM specimens, there are outside variables- such as dust or debris- that could have influenced these changes to the surface morphology. Imaging could have been in an area of the sample that might not be representative of the entire specimen as a whole. Baseline samples for SEM were not stored in 10 ml of deionized water, as the experimental specimens were and this may also account for any differences seen between the control specimens and the experimental specimens.

Another limitation, specific to the Opal group, was that there was only one surface that the Opal Seal was applied to during the fabrication of the specimens. This was done in order to replicate what would be done clinically. However, because there were two different surfaces, it is uncertain as to which surface was imaged under the SEM, as it was not indicated in the specimens after fabrication, and was not identifiable by an untrained eye.

Chapter 5: Conclusion

There were significant differences in release and re-release of fluoride among all four adhesives at different time intervals over a period of eight weeks. Significant increase in fluoride re-release was seen for all three of the recharge subgroups for both Opal and Transbond at each time interval. A significant increase in fluoride re-release for the Illuminate group was mainly observed at the end of second and fourth week. Though no significant increase in fluoride re-release was observed, Fuji released highest amount of fluoride during release and re-release, at all different time intervals. Fluoride varnish was the superior recharge material, as it provided the greatest fluoride measurements, followed by foam and toothpaste. There were observable changes in the surface morphology of the materials pre-experiment and post-experiment at a magnification of 50X and 500X, which may have an affect on the fluoride releasing capabilities of the materials.

Table 1. Descriptive Statistics: Initial Fluoride Release (1st Four Weeks)

Times		H2O	Fuji	Illuminate	Opal	Transbond
1 hour	Mean	0.012	3.503	2.353	0.032	0.008
	SD	0.003	0.546	0.418	0.011	0.002
24 hours	Mean	0.017	9.784	7.829	0.050	0.011
	SD	0.005	0.647	1.485	0.020	0.003
3 days	Mean	0.014	7.491	4.765	0.030	0.008
	SD	0.004	0.610	1.050	0.006	0.002
1 week	Mean	0.011	9.479	4.571	0.027	0.014
	SD	0.002	0.805	1.228	0.004	0.003
2 weeks	Mean	0.015	9.615	4.708	0.034	0.013
	SD	0.005	0.948	1.621	0.009	0.004
3 weeks	Mean	0.012	6.315	3.492	0.030	0.010
	SD	0.002	0.563	1.654	0.003	0.000
4 weeks	Mean	0.011	6.677	3.818	0.064	0.012
	SD	0.001	0.785	1.838	0.013	0.001
Mean		0.013	7.552	4.505	0.038	0.011

Table 2. Descriptive Statistics: Fluoride Re-release (2nd Four Weeks)

		Group							
		Fuji Data		Illuminate Data		Opal Data		Transbond Data	
Time	**Recharge**	**Mean**	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**
1 hour	Foam	5.61	1.51	2.16	1.20	3.06	0.71	0.70	0.89
	Paste	0.88	0.15	0.24	0.13	0.11	0.10	0.11	0.12
	Varnish	1.54	0.88	0.78	0.32	1.05	0.22	0.86	0.19
24 hours	Foam	1.95	0.29	0.81	0.42	0.29	0.02	0.03	0.01
	Paste	1.35	0.13	0.47	0.31	0.04	0.01	0.02	0.00
	Varnish	4.63	1.65	7.35	2.60	5.79	2.14	5.66	3.25
3 days	Foam	2.88	0.23	1.66	0.92	0.24	0.38	0.04	0.01
	Paste	2.06	0.13	1.30	0.74	0.05	0.01	0.03	0.00
	Varnish	6.23	1.24	6.81	2.42	5.89	1.16	4.89	1.62
1 week	Foam	4.24	0.13	3.48	2.19	0.11	0.02	0.04	0.00
	Paste	3.46	0.24	2.99	1.59	0.05	0.01	0.03	0.00
	Varnish	6.36	1.37	6.23	2.11	5.11	1.43	4.51	1.99
2 weeks	Foam	6.25	0.66	7.47	4.40	0.11	0.01	0.03	0.01
	Paste	5.95	0.36	5.93	3.11	0.06	0.01	0.03	0.00
	Varnish	9.16	1.53	7.54	3.11	5.30	2.45	3.75	1.67
3 weeks	Foam	6.77	0.22	6.74	3.90	0.09	0.01	0.04	0.01
	Paste	6.09	0.26	5.39	2.69	0.07	0.01	0.03	0.00
	Varnish	10.62	4.49	5.51	2.69	3.38	1.40	2.52	2.29
4 weeks	Foam	5.24	0.16	6.46	3.53	0.33	0.39	0.04	0.01
	Paste	5.11	0.28	5.37	2.53	0.07	0.01	0.03	0.00
	Varnish	8.30	3.58	4.61	1.55	2.50	1.09	1.72	1.82
Mean		4.985		4.252		1.605		1.196	

Table 3. Mixed Model Statistics: Overall Initial Fluoride Release

Group		Group	Difference	Lower CL	Upper CL	p-Value
Fuji	vs	H2O	7.539	7.245	7.833	*p < 0.05*
Illuminate	vs	H2O	4.492	4.198	4.786	*p < 0.05*
Opal	vs	H2O	0.025	-0.269	0.319	*NS*
Transbond	vs	H2O	-0.002	-0.296	0.292	*NS*
Illuminate	vs	Fuji	-3.047	-3.255	-2.839	*p < 0.05*
Opal	vs	Fuji	-7.514	-7.722	-7.306	*p < 0.05*
Transbond	vs	Fuji	-7.541	-7.749	-7.333	*p < 0.05*
Opal	vs	Illuminate	-4.467	-4.675	-4.259	*p < 0.05*
Transbond	vs	Illuminate	-4.494	-4.702	-4.286	*p < 0.05*
Transbond	vs	Opal	-0.027	-0.235	0.181	*NS*

Table 4. Mixed Model Statistics: Overall Fluoride Re-release

Group	Group	Difference	Lower CL	Upper CL	p-Value
Fuji	Transbond	3.791	3.001	4.581	*p < 0.05*
Fuji	Opal	3.379	2.589	4.169	*p < 0.05*
Illuminate	Transbond	3.058	2.268	3.848	*p < 0.05*
Illuminate	Opal	2.646	1.856	3.436	*p < 0.05*
Fuji	Illuminate	0.733	-0.057	1.523	*NS*
Opal	Transbond	0.411	-0.378	1.201	*NS*

Table 5. Mixed Model Statistics: Subgroups Fluoride Re-release

Subgroup	Subgroup	Difference	Lower CL	Upper CL	p-Value
Fuji,Varnish	Transbond,Paste	6.653	4.902	8.405	<.0001*
Fuji,Varnish	Opal ,Paste	6.626	4.874	8.377	<.0001*
Fuji,Varnish	Transbond,Foam	6.561	4.810	8.313	<.0001*
Fuji,Varnish	Opal ,Foam	6.086	4.335	7.838	<.0001*
Illuminate,Varnish	Transbond,Paste	5.508	3.757	7.260	<.0001*
Illuminate,Varnish	Opal ,Paste	5.481	3.729	7.232	<.0001*
Illuminate,Varnish	Transbond,Foam	5.416	3.664	7.168	<.0001*
Illuminate,Varnish	Opal ,Foam	4.941	3.189	6.693	<.0001*
Fuji,Foam	Transbond,Paste	4.668	2.917	6.420	<.0001*
Fuji,Foam	Opal ,Paste	4.641	2.889	6.392	<.0001*
Fuji,Foam	Transbond,Foam	4.576	2.824	6.328	<.0001*
Opal ,Varnish	Transbond,Paste	4.109	2.358	5.861	<.0001*
Fuji,Foam	Opal ,Foam	4.101	2.349	5.853	<.0001*
Opal ,Varnish	Opal ,Paste	4.082	2.330	5.833	<.0001*
Illuminate,Foam	Transbond,Paste	4.074	2.322	5.825	<.0001*
Illuminate,Foam	Opal ,Paste	4.046	2.295	5.798	<.0001*
Opal ,Varnish	Transbond,Foam	4.017	2.265	5.769	<.0001*
Illuminate,Foam	Transbond,Foam	3.982	2.230	5.733	<.0001*
Fuji,Varnish	Illuminate,Paste	3.592	1.841	5.344	<.0001*
Opal ,Varnish	Opal ,Foam	3.542	1.790	5.294	<.0001*
Fuji,Paste	Transbond,Paste	3.520	1.769	5.272	<.0001*
Illuminate,Foam	Opal ,Foam	3.507	1.755	5.258	<.0001*
Fuji,Paste	Opal ,Paste	3.492	1.741	5.244	<.0001*
Fuji,Paste	Transbond,Foam	3.428	1.676	5.179	<.0001*
Transbond,Varnish	Transbond,Paste	3.378	1.626	5.129	<.0001*
Transbond,Varnish	Opal ,Paste	3.350	1.598	5.102	<.0001*
Transbond,Varnish	Transbond,Foam	3.285	1.534	5.037	<.0001*
Fuji,Varnish	Transbond,Varnish	3.276	1.524	5.027	<.0001*
Fuji,Varnish	Fuji,Paste	3.133	1.382	4.885	<.0001*
Illuminate,Paste	Transbond,Paste	3.061	1.310	4.813	<.0001*
Illuminate,Paste	Opal ,Paste	3.034	1.282	4.785	<.0001*
Illuminate,Paste	Transbond,Foam	2.969	1.217	4.721	<.0001*
Fuji,Paste	Opal ,Foam	2.953	1.201	4.704	<.0001*
Transbond,Varnish	Opal ,Foam	2.810	1.059	4.562	<.0001*
Fuji,Varnish	Illuminate,Foam	2.580	0.828	4.331	0.0002*
Fuji,Varnish	Opal ,Varnish	2.544	0.793	4.296	0.0003*
Illuminate,Paste	Opal ,Foam	2.494	0.742	4.246	0.0004*
Illuminate,Varnish	Illuminate,Paste	2.447	0.695	4.199	0.0005*
Illuminate,Varnish	Transbond,Varnish	2.131	0.379	3.882	0.0050*

Subgroup	Subgroup	Difference	Lower CL	Upper CL	p-Value
Illuminate,Varnish	Fuji,Paste	1.988	0.236	3.740	0.0126*
Fuji,Varnish	Fuji,Foam	1.985	0.234	3.737	0.0128*
Fuji,Foam	Illuminate,Paste	1.607	-0.145	3.359	*NS*
Illuminate,Varnish	Illuminate,Foam	1.434	-0.317	3.186	*NS*
Illuminate,Varnish	Opal ,Varnish	1.399	-0.353	3.150	*NS*
Fuji,Foam	Transbond,Varnish	1.291	-0.461	3.042	*NS*
Fuji,Foam	Fuji,Paste	1.148	-0.604	2.900	*NS*
Fuji,Varnish	Illuminate,Varnish	1.145	-0.606	2.897	*NS*
Opal ,Varnish	Illuminate,Paste	1.048	-0.703	2.800	*NS*
Illuminate,Foam	Illuminate,Paste	1.013	-0.739	2.764	*NS*
Illuminate,Varnish	Fuji,Foam	0.840	-0.912	2.592	*NS*
Opal ,Varnish	Transbond,Varnish	0.732	-1.020	2.483	*NS*
Illuminate,Foam	Transbond,Varnish	0.696	-1.056	2.448	*NS*
Fuji,Foam	Illuminate,Foam	0.594	-1.157	2.346	*NS*
Opal ,Varnish	Fuji,Paste	0.589	-1.162	2.341	*NS*
Opal ,Foam	Transbond,Paste	0.567	-1.184	2.319	*NS*
Fuji,Foam	Opal ,Varnish	0.559	-1.193	2.310	*NS*
Illuminate,Foam	Fuji,Paste	0.554	-1.198	2.305	*NS*
Opal ,Foam	Opal ,Paste	0.540	-1.212	2.291	*NS*
Opal ,Foam	Transbond,Foam	0.475	-1.277	2.227	*NS*
Fuji,Paste	Illuminate,Paste	0.459	-1.293	2.211	*NS*
Transbond,Varnish	Illuminate,Paste	0.316	-1.435	2.068	*NS*
Fuji,Paste	Transbond,Varnish	0.142	-1.609	1.894	*NS*
Transbond,Foam	Transbond,Paste	0.092	-1.659	1.844	*NS*
Transbond,Foam	Opal ,Paste	0.065	-1.687	1.816	*NS*
Opal ,Varnish	Illuminate,Foam	0.036	-1.716	1.787	*NS*
Opal ,Paste	Transbond,Paste	0.028	-1.724	1.779	*NS*

Table 6. Paired T-test Pre vs. Post Recharge within Groups at 24 hours

		Fluoride Release (mean±SD) @ 24 hours			
		Pre Recharge	Post Recharge	Diff	p-value
Illuminate	***Foam***	7.6±1.3	0.8±0.4	6.8±1.0	<0.0001
	Paste	7.9±1.9	0.5±0.3	7.4±1.8	<0.0001
	Varnish	8.0±1.3	7.3±2.6	0.7±2.9	0.48
Opal	***Foam***	0.044±0.01	0.29±0.017	-0.24±0.02	<0.0001
	Paste	0.051±0.03	0.043±0.00	0.009±0.03	0.33
	Varnish	0.053±0.02	5.79±2.14	-5.74±2.13	<0.000
Transbond	***Foam***	0.012±0.00	0.029±0.00	-0.017±0.00	<0.0001
	Paste	0.011±0.00	0.019±0.00	-0.007±0.00	<0.0001
	Varnish	0.019±0.00	5.67±3.24	-5.65±3.24	0.0004
Fuji	***Foam***	9.73±0.72	1.95±0.29	7.78±0.61	<0.0001
	Paste	9.84±0.66	1.35±0.13	8.49±0.59	<0.0001
	Varnish	9.78±0.634	4.63±1.65	5.15±3.7	<0.0001

Table 7. Paired T-test Pre vs. Post Recharge within Groups at 2 Weeks

		Fluoride Release (mean±SD) @ 2 weeks			
		Pre Recharge	**Post Recharge**	**Diff**	**p-value**
Illuminate	***Foam***	4.4±2.1	7.5±4.4	-3.0±3.0	0.01
	Paste	4.4±1.3	5.9±3.1	-1.5±2.1	0.05
	Varnish	5.3±1.4	7.5±3.1	-2.3±3.0	0.04
Opal	***Foam***	0.035±0.00	0.12±0.01	-0.074±0.01	<0.0001
	Paste	0.033±0.00	0.06±0.00	-0.027±0.00	<0.0001
	Varnish	0.035±0.01	5.3±2.45	-5.27±2.45	<0.000
Transbond	***Foam***	0.014±0.00	0.034±0.00	-0.021±0.00	0.0003
	Paste	0.012±0.00	0.025±0.00	-0.013±0.00	<0.0001
	Varnish	0.013±0.00	3.75±1.67	-3.74±1.67	<0.0001
Fuji	***Foam***	9.57±0.76	6.2±0.66	3.33±1.04	<0.0001
	Paste	9.56±1.02	5.95±0.34	3.61±0.80	<0.0001
	Varnish	9.71±1.12	9.12±1.53	0.55±2.24	0.45

Table 8. Paired T-test Pre vs. Post Recharge within Groups at 4 Weeks

		Fluoride Release (mean±SD) @ 4 weeks			
		Pre Recharge	Post Recharge	Diff	p-value
Illuminate	***Foam***	3.6±2.1	6.5±3.5	-2.9±2.2	0.003
	Paste	3.3±1.5	5.4±2.5	-2.1±1.1	0.003
	Varnish	4.6±1.8	4.6±1.5	-0.01±1.0	0.95
Opal	***Foam***	0.065±0.01	0.33±0.39	-0.27±0.38	0.05
	Paste	0.061±0.01	0.071±0.00	-0.009±0.01	0.02
	Varnish	0.066±0.02	2.50±1.1	-2.44±1.1	<0.000
Transbond	***Foam***	0.012±0.00	0.039±0.00	-0.031±0.00	<0.0001
	Paste	0.013±0.00	0.30±0.00	-0.017±0.00	<0.0001
	Varnish	0.013±0.00	1.72±1.81	-1.71±1.82	0.01
Fuji	***Foam***	6.37±0.89	5.24±0.16	1.14±1.0	0.005
	Paste	6.72±0.80	5.11±0.28	1.61±2.12	<0.0001
	Varnish	6.93±0.61	8.3±3.58	-1.36±3.91	0.29

Table 9. Pre vs. Post Recharge Differences between Groups at 24 Hours

Group	Recharge		Group	Recharge	Difference	Lower 95% CI	Upper 95% CI	Sig
Illuminate	Foam	vs	Illuminate	Varnish	-6.537	-8.775	-4.300	$p< 0.05$
Illuminate	Paste	vs	Illuminate	Varnish	-6.873	-9.110	-4.635	$p< 0.05$
Transbond	Varnish	vs	Illuminate	Varnish	-1.688	-3.925	0.549	*NS*
Transbond	Foam	vs	Illuminate	Varnish	-7.317	-9.555	-5.080	$p< 0.05$
Transbond	Paste	vs	Illuminate	Varnish	-7.328	-9.565	-5.091	$p< 0.05$
Opal	Varnish	vs	Illuminate	Varnish	-1.554	-3.791	0.683	*NS*
Opal	Foam	vs	Illuminate	Varnish	-7.058	-9.295	-4.821	$p< 0.05$
Opal	Paste	vs	Illuminate	Varnish	-7.058	-9.295	-4.821	$p< 0.05$
Fuji	Varnish	vs	Illuminate	Varnish	-2.718	-4.955	-0.481	$p< 0.05$
Fuji	Foam	vs	Illuminate	Varnish	-5.395	-7.632	-3.158	$p< 0.05$
Fuji	Paste	vs	Illuminate	Varnish	-5.996	-8.234	-3.759	$p< 0.05$
Illuminate	Paste	vs	Illuminate	Foam	-0.335	-2.572	1.902	*NS*
Transbond	Varnish	vs	Illuminate	Foam	4.849	2.612	7.087	$p< 0.05$
Transbond	Foam	vs	Illuminate	Foam	-0.780	-3.017	1.457	*NS*
Transbond	Paste	vs	Illuminate	Foam	-0.790	-3.027	1.447	*NS*
Opal	Varnish	vs	Illuminate	Foam	4.983	2.746	7.221	$p< 0.05$
Opal	Foam	vs	Illuminate	Foam	-0.521	-2.758	1.717	*NS*
Opal	Paste	vs	Illuminate	Foam	-0.521	-2.758	1.717	*NS*
Fuji	Varnish	vs	Illuminate	Foam	3.819	1.582	6.057	$p< 0.05$
Fuji	Foam	vs	Illuminate	Foam	1.142	-1.095	3.379	*NS*
Fuji	Paste	vs	Illuminate	Foam	0.541	-1.696	2.778	*NS*
Transbond	Varnish	vs	Illuminate	Paste	5.185	2.947	7.422	*NS*
Transbond	Foam	vs	Illuminate	Paste	-0.445	-2.682	1.792	*NS*
Transbond	Paste	vs	Illuminate	Paste	-0.455	-2.692	1.782	*NS*
Opal	Varnish	vs	Illuminate	Paste	5.319	3.081	7.556	$p< 0.05$
Opal	Foam	vs	Illuminate	Paste	-0.185	-2.423	2.052	*NS*
Opal	Paste	vs	Illuminate	Paste	-0.185	-2.423	2.052	*NS*
Fuji	Varnish	vs	Illuminate	Paste	4.155	1.917	6.392	*NS*
Fuji	Foam	vs	Illuminate	Paste	1.477	-0.760	3.715	*NS*
Fuji	Paste	vs	Illuminate	Paste	0.876	-1.361	3.113	*NS*
Transbond	Foam	vs	Transbond	Varnish	-5.629	-7.867	-3.392	$p< 0.05$
Transbond	Paste	vs	Transbond	Varnish	-5.640	-7.877	-3.403	$p< 0.05$
Opal	Varnish	vs	Transbond	Varnish	0.134	-2.103	2.371	*NS*
Opal	Foam	vs	Transbond	Varnish	-5.370	-7.607	-3.133	$p< 0.05$
Opal	Paste	vs	Transbond	Varnish	-5.370	-7.607	-3.133	$p< 0.05$
Fuji	Varnish	vs	Transbond	Varnish	-1.030	-3.267	1.207	*NS*
Fuji	Foam	vs	Transbond	Varnish	-3.707	-5.944	-1.470	$p< 0.05$
Fuji	Paste	vs	Transbond	Varnish	-4.308	-6.546	-2.071	$p< 0.05$
Transbond	Paste	vs	Transbond	Foam	-0.010	-2.247	2.227	*NS*
Opal	Varnish	vs	Transbond	Foam	5.763	3.526	8.001	$p< 0.05$
Opal	Foam	vs	Transbond	Foam	0.259	-1.978	2.497	*NS*
Opal	Paste	vs	Transbond	Foam	0.259	-1.978	2.497	*NS*
Fuji	Varnish	vs	Transbond	Foam	4.599	2.362	6.837	$p< 0.05$

Group	Recharge		Group	Recharge	Difference	Lower 95% CI	Upper 95% CI	Sig
Fuji	Foam	vs	Transbond	Foam	1.922	-0.315	4.159	*NS*
Fuji	Paste	vs	Transbond	Foam	1.321	-0.916	3.558	*NS*
Opal	Varnish	vs	Transbond	Paste	5.774	3.537	8.011	$p< 0.05$
Opal	Foam	vs	Transbond	Paste	0.270	-1.967	2.507	*NS*
Opal	Paste	vs	Transbond	Paste	0.270	-1.967	2.507	*NS*
Fuji	Varnish	vs	Transbond	Paste	4.610	2.373	6.847	$p< 0.05$
Fuji	Foam	vs	Transbond	Paste	1.933	-0.305	4.170	*NS*
Fuji	Paste	vs	Transbond	Paste	1.331	-0.906	3.568	*NS*
Opal	Foam	vs	Opal	Varnish	-5.504	-7.741	-3.267	$p< 0.05$
Opal	Paste	vs	Opal	Varnish	-5.504	-7.741	-3.267	$p< 0.05$
Fuji	Varnish	vs	Opal	Varnish	-1.164	-3.401	1.073	*NS*
Fuji	Foam	vs	Opal	Varnish	-3.841	-6.078	-1.604	$p< 0.05$
Fuji	Paste	vs	Opal	Varnish	-4.442	-6.680	-2.205	$p< 0.05$
Opal	Paste	vs	Opal	Foam	-0.000	-2.237	2.237	*NS*
Fuji	Varnish	vs	Opal	Foam	4.340	2.103	6.577	$p< 0.05$
Fuji	Foam	vs	Opal	Foam	1.663	-0.574	3.900	*NS*
Fuji	Paste	vs	Opal	Foam	1.062	-1.176	3.299	*NS*
Fuji	Varnish	vs	Opal	Paste	4.340	2.103	6.577	$p< 0.05$
Fuji	Foam	vs	Opal	Paste	1.663	-0.574	3.900	*NS*
Fuji	Paste	vs	Opal	Paste	1.062	-1.176	3.299	*NS*
Fuji	Foam	vs	Fuji	Varnish	-2.677	-4.914	-0.440	$p< 0.05$
Fuji	Paste	vs	Fuji	Varnish	-3.278	-5.516	-1.041	$p< 0.05$
Fuji	Paste	vs	Fuji	Foam	-0.601	-2.838	1.636	*NS*

Table 10. Pre vs. Post Recharge Differences between Groups at 2 Weeks

Group	Recharge		Group	Recharge	Difference	Lower 95% CI	Upper 95% CI	Sig
Illuminate	Foam	vs	Illuminate	Varnish	-0.068	-3.244	3.108	NS
Illuminate	Paste	vs	Illuminate	Varnish	-1.608	-4.784	1.568	NS
Transbond	Varnish	vs	Illuminate	Varnish	-3.793	-6.969	-0.617	p < 0.05
Transbond	Foam	vs	Illuminate	Varnish	-7.505	-10.681	-4.330	p < 0.05
Transbond	Paste	vs	Illuminate	Varnish	-7.515	-10.690	-4.339	p < 0.05
Opal	Varnish	vs	Illuminate	Varnish	-2.240	-5.416	0.936	NS
Opal	Foam	vs	Illuminate	Varnish	-7.432	-10.607	-4.256	p < 0.05
Opal	Paste	vs	Illuminate	Varnish	-7.432	-10.607	-4.256	p < 0.05
Fuji	Varnish	vs	Illuminate	Varnish	1.618	-1.558	4.794	NS
Fuji	Foam	vs	Illuminate	Varnish	-1.294	-4.470	1.882	NS
Fuji	Paste	vs	Illuminate	Varnish	-1.586	-4.762	1.590	NS
Illuminate	Paste	vs	Illuminate	Foam	-1.540	-4.716	1.636	NS
Transbond	Varnish	vs	Illuminate	Foam	-3.725	-6.901	-0.549	p < 0.05
Transbond	Foam	vs	Illuminate	Foam	-7.437	-10.613	-4.262	p < 0.05
Transbond	Paste	vs	Illuminate	Foam	-7.447	-10.622	-4.271	p < 0.05
Opal	Varnish	vs	Illuminate	Foam	-2.172	-5.348	1.004	NS
Opal	Foam	vs	Illuminate	Foam	-7.364	-10.539	-4.188	p < 0.05
Opal	Paste	vs	Illuminate	Foam	-7.364	-10.539	-4.188	p < 0.05
Fuji	Varnish	vs	Illuminate	Foam	1.686	-1.490	4.862	NS
Fuji	Foam	vs	Illuminate	Foam	-1.226	-4.402	1.950	NS
Fuji	Paste	vs	Illuminate	Foam	-1.518	-4.694	1.658	NS
Transbond	Varnish	vs	Illuminate	Paste	-2.185	-5.361	0.991	NS
Transbond	Foam	vs	Illuminate	Paste	-5.897	-9.073	-2.722	p < 0.05
Transbond	Paste	vs	Illuminate	Paste	-5.907	-9.082	-2.731	p < 0.05
Opal	Varnish	vs	Illuminate	Paste	-0.632	-3.808	2.544	NS
Opal	Foam	vs	Illuminate	Paste	-5.824	-8.999	-2.648	p < 0.05
Opal	Paste	vs	Illuminate	Paste	-5.824	-8.999	-2.648	p < 0.05
Fuji	Varnish	vs	Illuminate	Paste	3.226	0.050	6.402	p < 0.05
Fuji	Foam	vs	Illuminate	Paste	0.314	-2.862	3.490	NS
Fuji	Paste	vs	Illuminate	Paste	0.022	-3.154	3.198	NS
Transbond	Foam	vs	Transbond	Varnish	-3.712	-6.888	-0.537	p < 0.05
Transbond	Paste	vs	Transbond	Varnish	-3.722	-6.897	-0.546	p < 0.05
Opal	Varnish	vs	Transbond	Varnish	1.553	-1.623	4.729	NS
Opal	Foam	vs	Transbond	Varnish	-3.639	-6.814	-0.463	p < 0.05
Opal	Paste	vs	Transbond	Varnish	-3.639	-6.814	-0.463	p < 0.05
Fuji	Varnish	vs	Transbond	Varnish	5.411	2.235	8.587	p < 0.05
Fuji	Foam	vs	Transbond	Varnish	2.499	-0.677	5.675	NS
Fuji	Paste	vs	Transbond	Varnish	2.207	-0.969	5.383	NS
Transbond	Paste	vs	Transbond	Foam	-0.010	-3.185	3.166	NS
Opal	Varnish	vs	Transbond	Foam	5.265	2.090	8.441	p < 0.05
Opal	Foam	vs	Transbond	Foam	0.073	-3.102	3.249	NS
Opal	Paste	vs	Transbond	Foam	0.073	-3.102	3.249	NS
Fuji	Varnish	vs	Transbond	Foam	9.123	5.948	12.299	p < 0.05

Group	Recharge		Group	Recharge	Difference	Lower 95% CI	Upper 95% CI	Sig
Fuji	Foam	vs	Transbond	Foam	6.211	3.036	9.387	p < 0.05
Fuji	Paste	vs	Transbond	Foam	5.919	2.744	9.095	p < 0.05
Opal	Varnish	vs	Transbond	Paste	5.275	2.099	8.450	p < 0.05
Opal	Foam	vs	Transbond	Paste	0.083	-3.093	3.259	NS
Opal	Paste	vs	Transbond	Paste	0.083	-3.093	3.259	NS
Fuji	Varnish	vs	Transbond	Paste	9.133	5.957	12.308	p < 0.05
Fuji	Foam	vs	Transbond	Paste	6.221	3.045	9.396	p < 0.05
Fuji	Paste	vs	Transbond	Paste	5.929	2.753	9.104	p < 0.05
Opal	Foam	vs	Opal	Varnish	-5.192	-8.367	-2.016	p < 0.05
Opal	Paste	vs	Opal	Varnish	-5.192	-8.367	-2.016	p < 0.05
Fuji	Varnish	vs	Opal	Varnish	3.858	0.682	7.034	p < 0.05
Fuji	Foam	vs	Opal	Varnish	0.946	-2.230	4.122	NS
Fuji	Paste	vs	Opal	Varnish	0.654	-2.522	3.830	NS
Opal	Paste	vs	Opal	Foam	0.000	-3.176	3.176	NS
Fuji	Varnish	vs	Opal	Foam	9.050	5.874	12.225	p < 0.05
Fuji	Foam	vs	Opal	Foam	6.138	2.962	9.313	p < 0.05
Fuji	Paste	vs	Opal	Foam	5.846	2.670	9.021	p < 0.05
Fuji	Varnish	vs	Opal	Paste	9.050	5.874	12.225	p < 0.05
Fuji	Foam	vs	Opal	Paste	6.138	2.962	9.313	p < 0.05
Fuji	Paste	vs	Opal	Paste	5.846	2.670	9.021	p < 0.05
Fuji	Foam	vs	Fuji	Varnish	-2.912	-6.088	0.264	NS
Fuji	Paste	vs	Fuji	Varnish	-3.204	-6.380	-0.028	p < 0.05
Fuji	Paste	vs	Fuji	Foam	-0.292	-3.468	2.884	NS

Table 11. Pre vs. Post Recharge Differences between Groups at 4 Weeks

Group	Recharge		Group	Recharge	Difference	Lower 95% CI	Upper 95% CI	Sig
Illuminate	Foam	vs	Illuminate	Varnish	1.846	-0.947	4.639	NS
Illuminate	Paste	vs	Illuminate	Varnish	0.764	-2.029	3.557	NS
Transbond	Varnish	vs	Illuminate	Varnish	-2.887	-5.680	-0.094	p < 0.05
Transbond	Foam	vs	Illuminate	Varnish	-4.571	-7.364	-1.778	p < 0.05
Transbond	Paste	vs	Illuminate	Varnish	-4.580	-7.373	-1.787	p < 0.05
Opal	Varnish	vs	Illuminate	Varnish	-2.107	-4.900	0.686	NS
Opal	Foam	vs	Illuminate	Varnish	-4.276	-7.069	-1.483	p < 0.05
Opal	Paste	vs	Illuminate	Varnish	-4.276	-7.069	-1.483	p < 0.05
Fuji	Varnish	vs	Illuminate	Varnish	3.688	0.895	6.481	p < 0.05
Fuji	Foam	vs	Illuminate	Varnish	0.632	-2.161	3.425	NS
Fuji	Paste	vs	Illuminate	Varnish	0.498	-2.295	3.291	NS
Illuminate	Paste	vs	Illuminate	Foam	-1.082	-3.875	1.711	NS
Transbond	Varnish	vs	Illuminate	Foam	-4.733	-7.526	-1.940	p < 0.05
Transbond	Foam	vs	Illuminate	Foam	-6.417	-9.210	-3.624	p < 0.05
Transbond	Paste	vs	Illuminate	Foam	-6.426	-9.219	-3.633	p < 0.05
Opal	Varnish	vs	Illuminate	Foam	-3.953	-6.746	-1.160	p < 0.05
Opal	Foam	vs	Illuminate	Foam	-6.122	-8.915	-3.329	p < 0.05
Opal	Paste	vs	Illuminate	Foam	-6.122	-8.915	-3.329	p < 0.05
Fuji	Varnish	vs	Illuminate	Foam	1.842	-0.951	4.635	NS
Fuji	Foam	vs	Illuminate	Foam	-1.214	-4.007	1.579	NS
Fuji	Paste	vs	Illuminate	Foam	-1.348	-4.141	1.445	NS
Transbond	Varnish	vs	Illuminate	Paste	-3.651	-6.444	-0.858	p < 0.05
Transbond	Foam	vs	Illuminate	Paste	-5.335	-8.128	-2.542	p < 0.05
Transbond	Paste	vs	Illuminate	Paste	-5.344	-8.137	-2.551	p < 0.05
Opal	Varnish	vs	Illuminate	Paste	-2.871	-5.664	-0.078	p < 0.05
Opal	Foam	vs	Illuminate	Paste	-5.040	-7.833	-2.247	p < 0.05
Opal	Paste	vs	Illuminate	Paste	-5.040	-7.833	-2.247	p < 0.05
Fuji	Varnish	vs	Illuminate	Paste	2.924	0.131	5.717	p < 0.05
Fuji	Foam	vs	Illuminate	Paste	-0.132	-2.925	2.661	NS
Fuji	Paste	vs	Illuminate	Paste	-0.266	-3.059	2.527	NS
Transbond	Foam	vs	Transbond	Varnish	-1.684	-4.477	1.109	NS
Transbond	Paste	vs	Transbond	Varnish	-1.693	-4.486	1.100	NS
Opal	Varnish	vs	Transbond	Varnish	0.780	-2.013	3.573	NS
Opal	Foam	vs	Transbond	Varnish	-1.389	-4.182	1.404	NS
Opal	Paste	vs	Transbond	Varnish	-1.389	-4.182	1.404	NS
Fuji	Varnish	vs	Transbond	Varnish	6.575	3.782	9.368	p < 0.05
Fuji	Foam	vs	Transbond	Varnish	3.519	0.726	6.312	p < 0.05
Fuji	Paste	vs	Transbond	Varnish	3.385	0.592	6.178	p < 0.05
Transbond	Paste	vs	Transbond	Foam	-0.009	-2.802	2.784	NS
Opal	Varnish	vs	Transbond	Foam	2.464	-0.329	5.257	NS
Opal	Foam	vs	Transbond	Foam	0.295	-2.498	3.088	NS
Opal	Paste	vs	Transbond	Foam	0.295	-2.498	3.088	NS

Group	Recharge		Group	Recharge	Difference	Lower 95% CI	Upper 95% CI	Sig
Fuji	Varnish	vs	Transbond	Foam	8.259	5.466	11.052	p < 0.05
Fuji	Foam	vs	Transbond	Foam	5.203	2.410	7.996	p < 0.05
Fuji	Paste	vs	Transbond	Foam	5.069	2.276	7.862	p < 0.05
Opal	Varnish	vs	Transbond	Paste	2.473	-0.320	5.266	NS
Opal	Foam	vs	Transbond	Paste	0.304	-2.489	3.097	NS
Opal	Paste	vs	Transbond	Paste	0.304	-2.489	3.097	NS
Fuji	Varnish	vs	Transbond	Paste	8.268	5.475	11.061	p < 0.05
Fuji	Foam	vs	Transbond	Paste	5.212	2.419	8.005	p < 0.05
Fuji	Paste	vs	Transbond	Paste	5.078	2.285	7.871	p < 0.05
Opal	Foam	vs	Opal	Varnish	-2.169	-4.962	0.624	NS
Opal	Paste	vs	Opal	Varnish	-2.169	-4.962	0.624	NS
Fuji	Varnish	vs	Opal	Varnish	5.795	3.002	8.588	p < 0.05
Fuji	Foam	vs	Opal	Varnish	2.739	-0.054	5.532	NS
Fuji	Paste	vs	Opal	Varnish	2.605	-0.188	5.398	NS
Opal	Paste	vs	Opal	Foam	0.000	-2.793	2.793	NS
Fuji	Varnish	vs	Opal	Foam	7.964	5.171	10.757	p < 0.05
Fuji	Foam	vs	Opal	Foam	4.908	2.115	7.701	p < 0.05
Fuji	Paste	vs	Opal	Foam	4.774	1.981	7.567	p < 0.05
Fuji	Varnish	vs	Opal	Paste	7.964	5.171	10.757	p < 0.05
Fuji	Foam	vs	Opal	Paste	4.908	2.115	7.701	p < 0.05
Fuji	Paste	vs	Opal	Paste	4.774	1.981	7.567	p < 0.05
Fuji	Foam	vs	Fuji	Varnish	-3.056	-5.849	-0.263	p < 0.05
Fuji	Paste	vs	Fuji	Varnish	-3.190	-5.983	-0.397	p < 0.05
Fuji	Paste	vs	Fuji	Foam	-0.134	-2.927	2.659	NS

Figure 1. Sample Flow Chart for each of the Materials

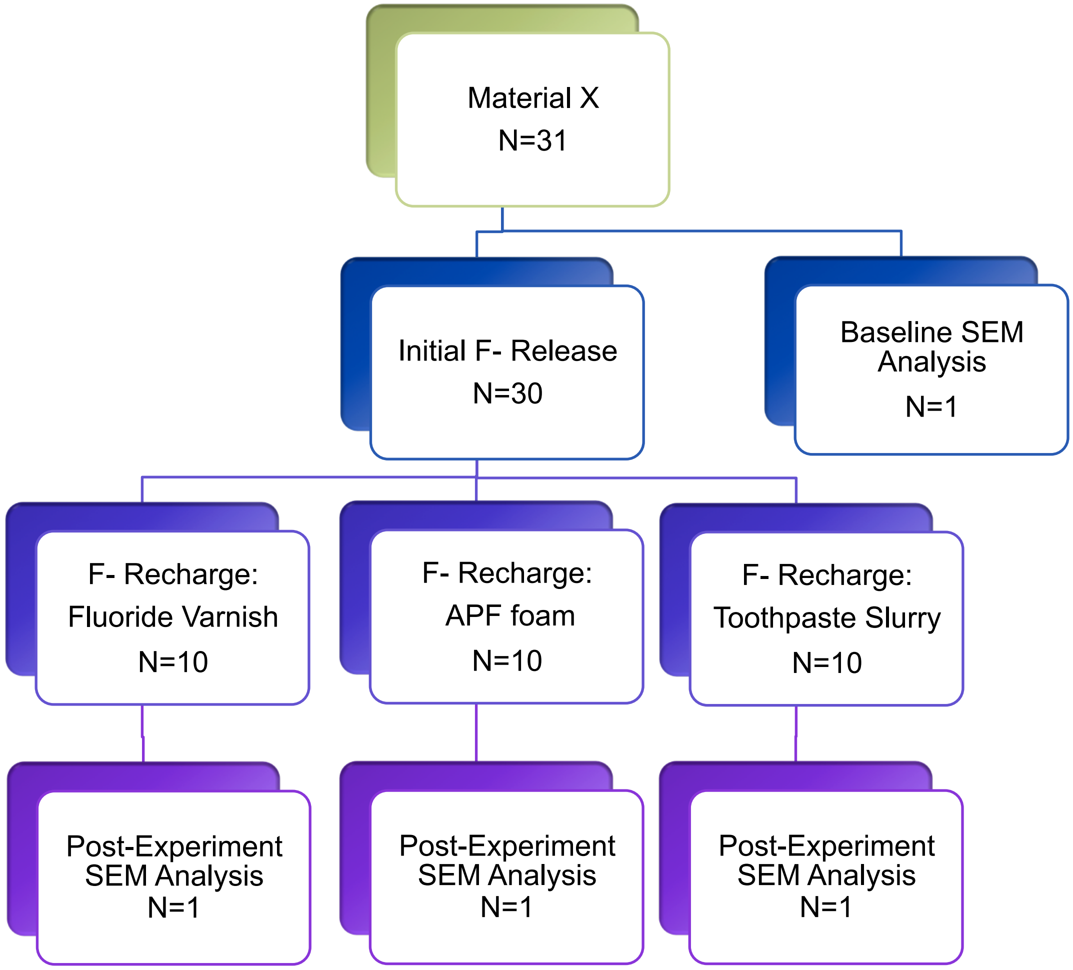


Figure 2. Orthodontic Bonding Materials

Figure 3. Sample Preparation

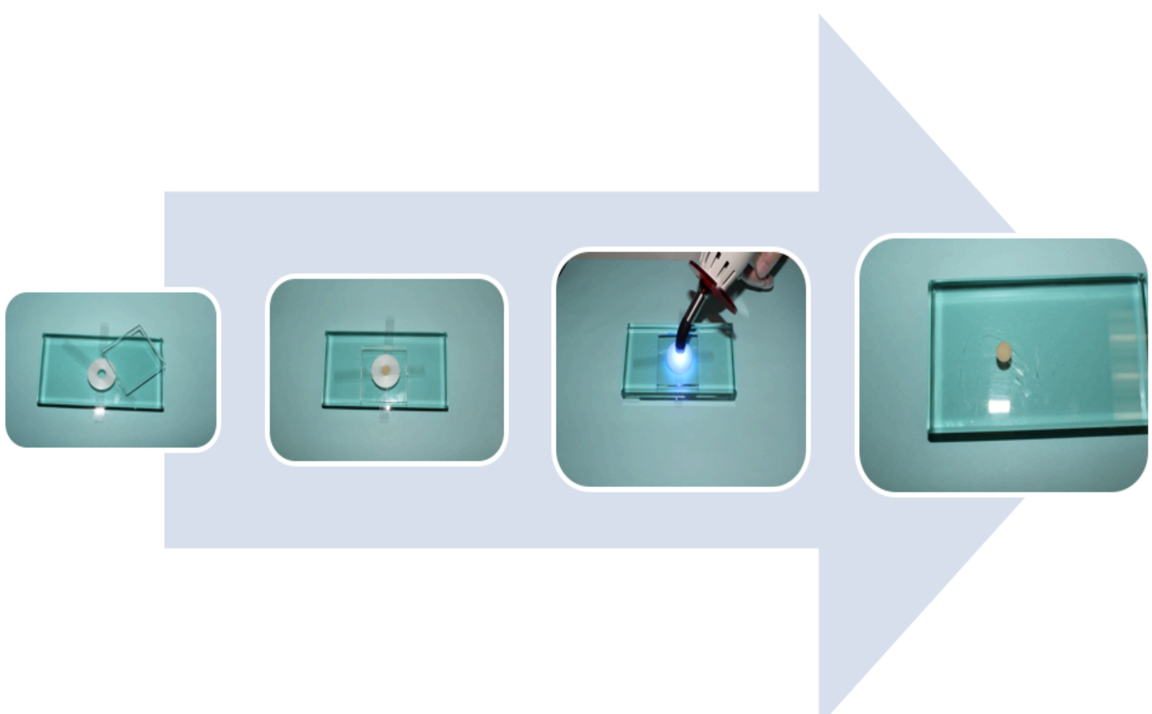


Figure 4. Samples in capped plastic containers with 10 ml deionized water

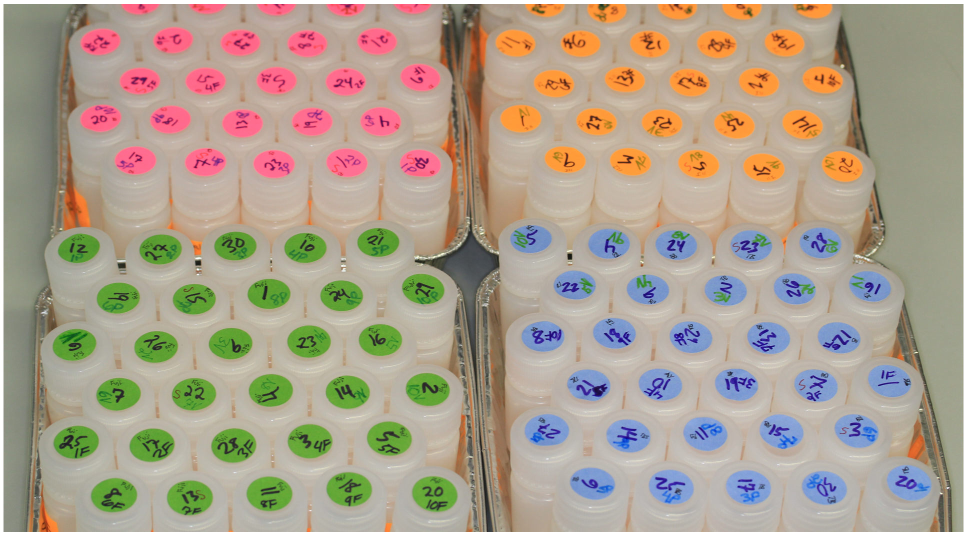


Figure 5. Incubator

Figure 6. Fluoride Meter

Figure 7. Rinse and Blot Dry

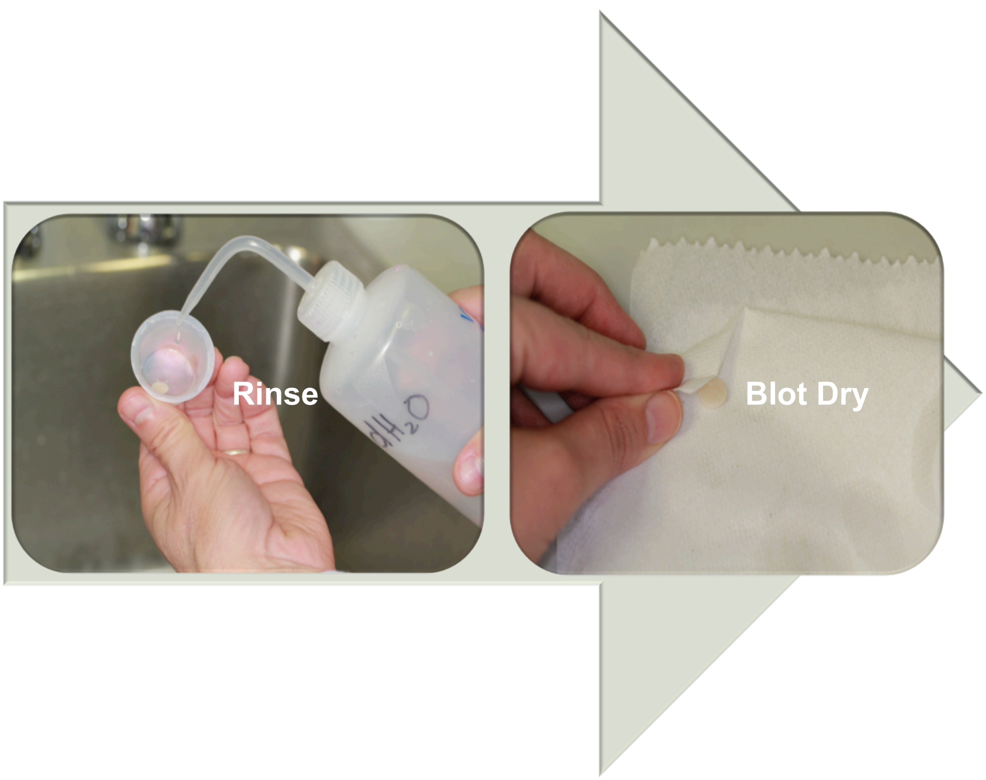


Figure 8. TISAB II in 1:1 ratio with sample solution for testing

Figure 9. Recharge Materials

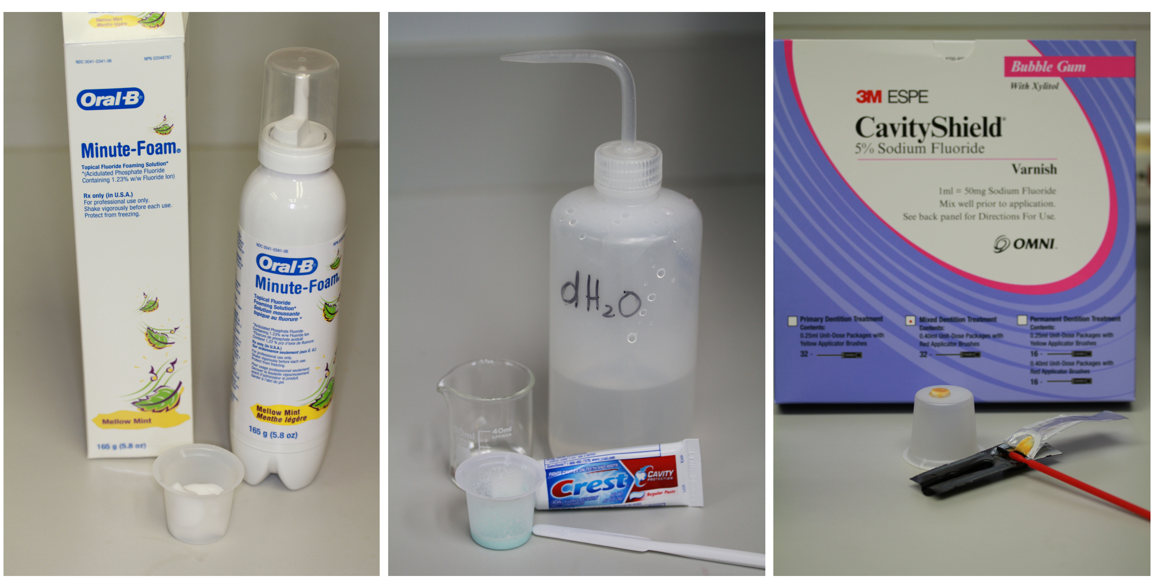


Figure 10. Scanning Electron Microscope

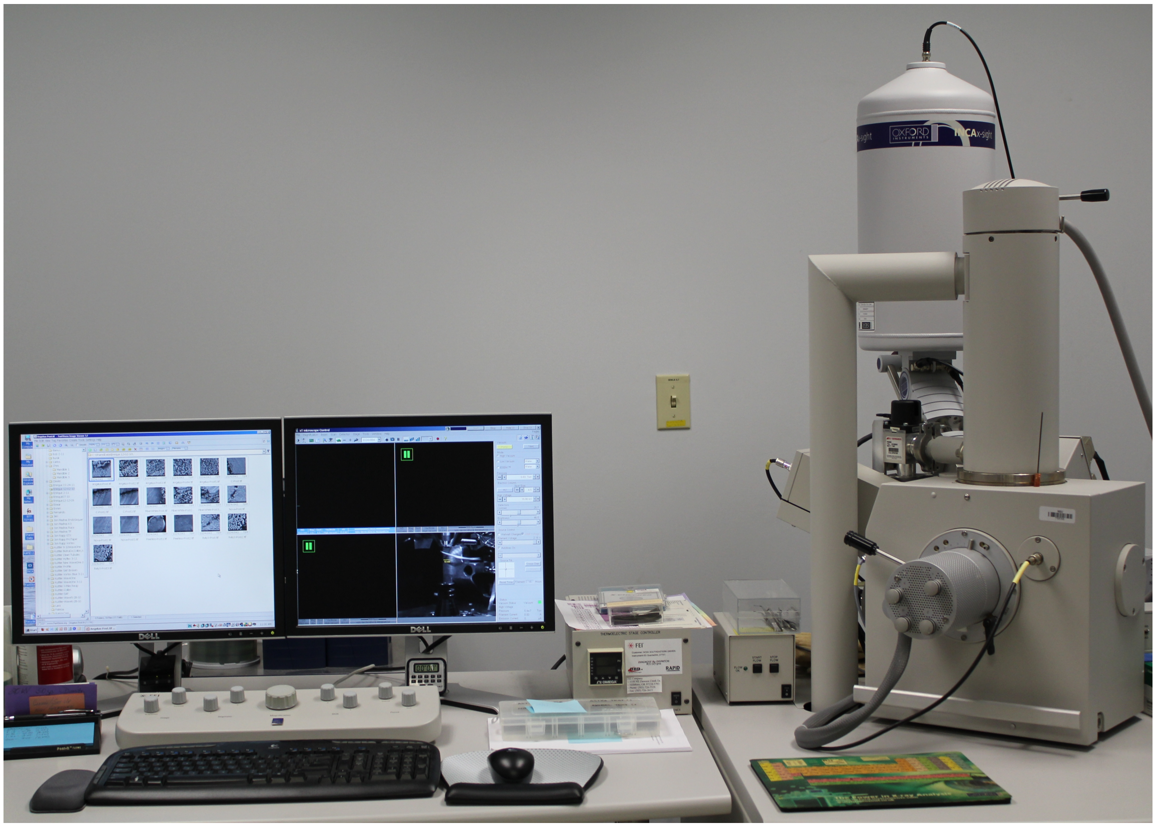


Figure 11. Graph of Fluoride Release: Initial Four Weeks

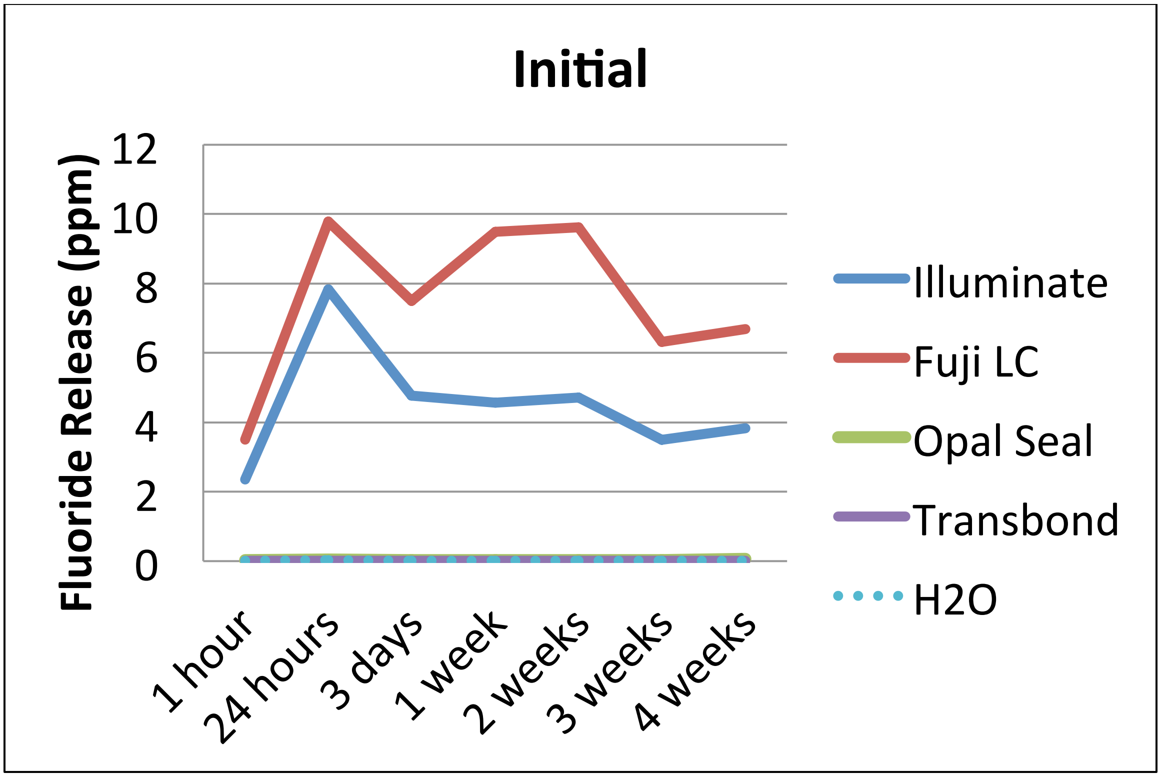


Figure 12. Graphs of Fluoride Re-release: Fuji (Second Four Weeks)

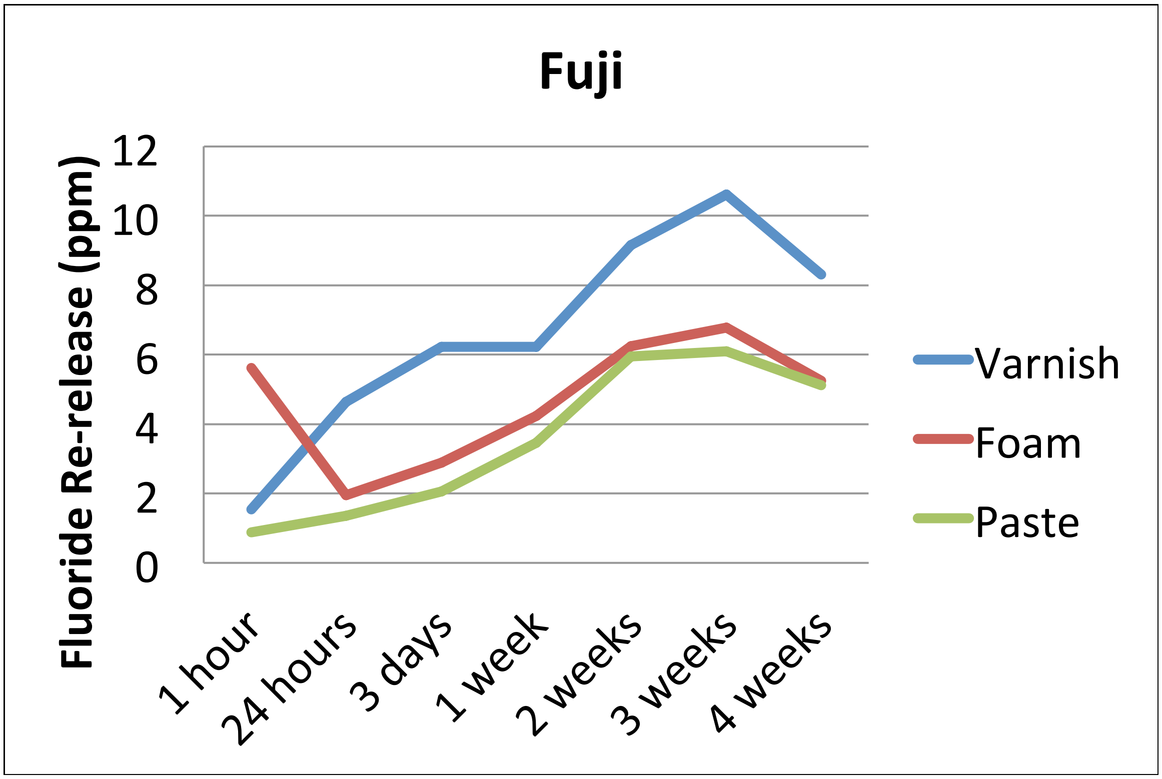


Figure 13. Graph of Fluoride Re-release: Illuminate (Second Four Weeks)

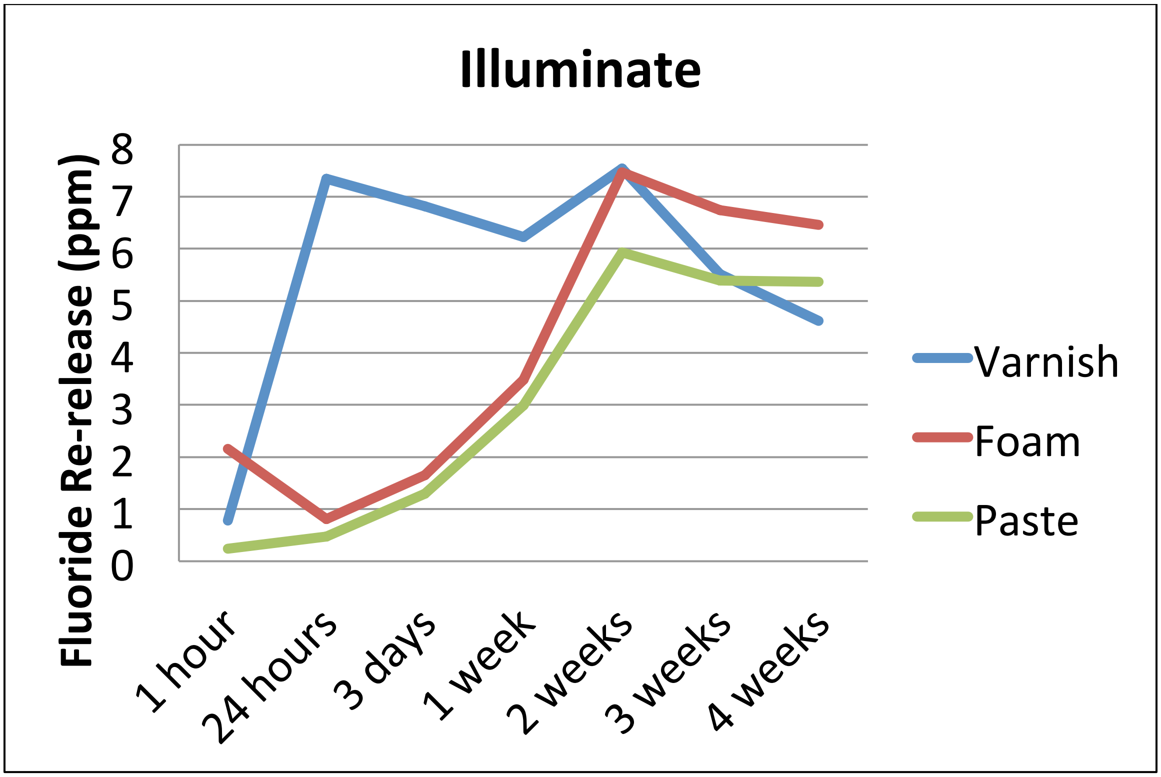


Figure 14. Graph of Fluoride Re-release: Transbond (Second Four Weeks)

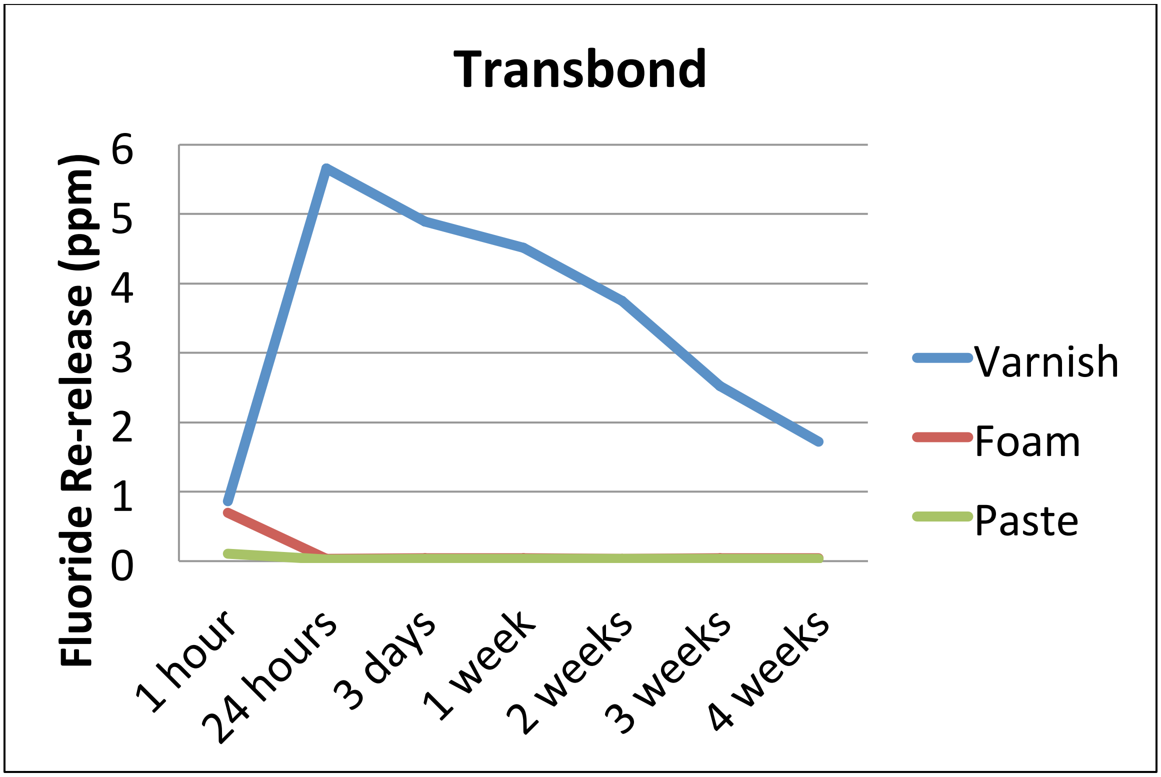


Figure 15. Graph of Fluoride Re-release: Opal (Second Four Weeks)

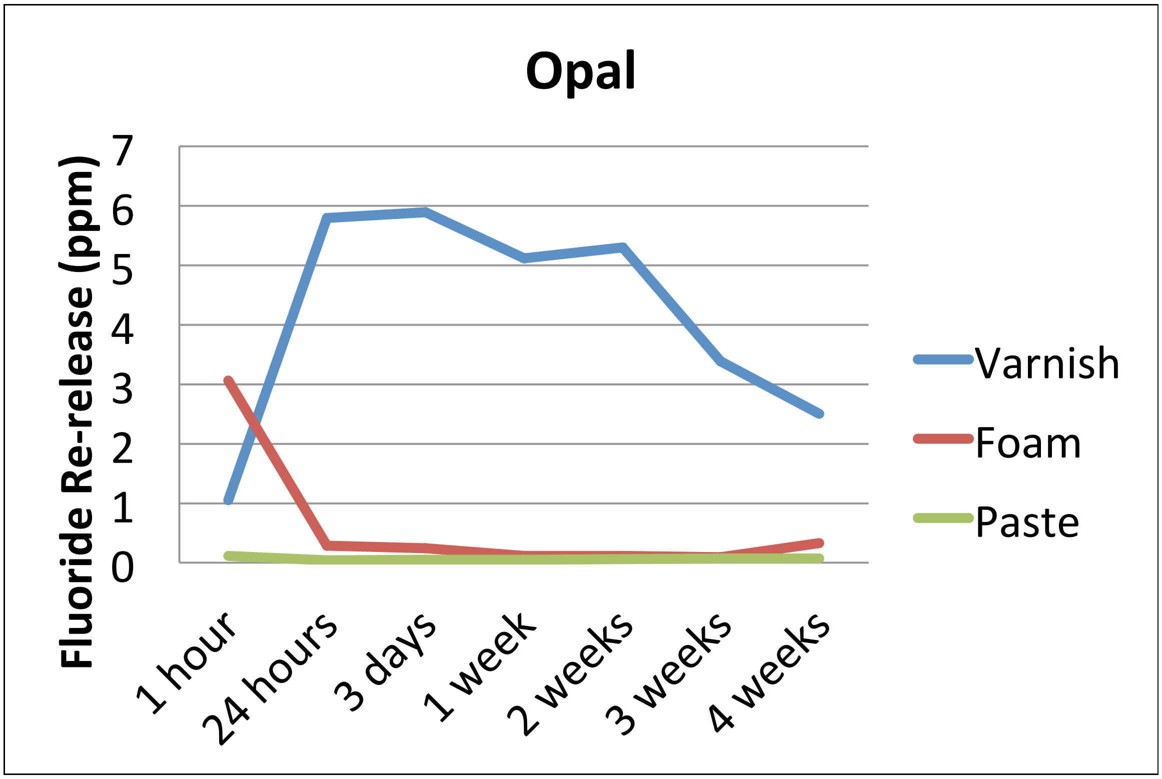


Figure 16. Graph of Overall Fluoride Release and Re-release (Eight Weeks)

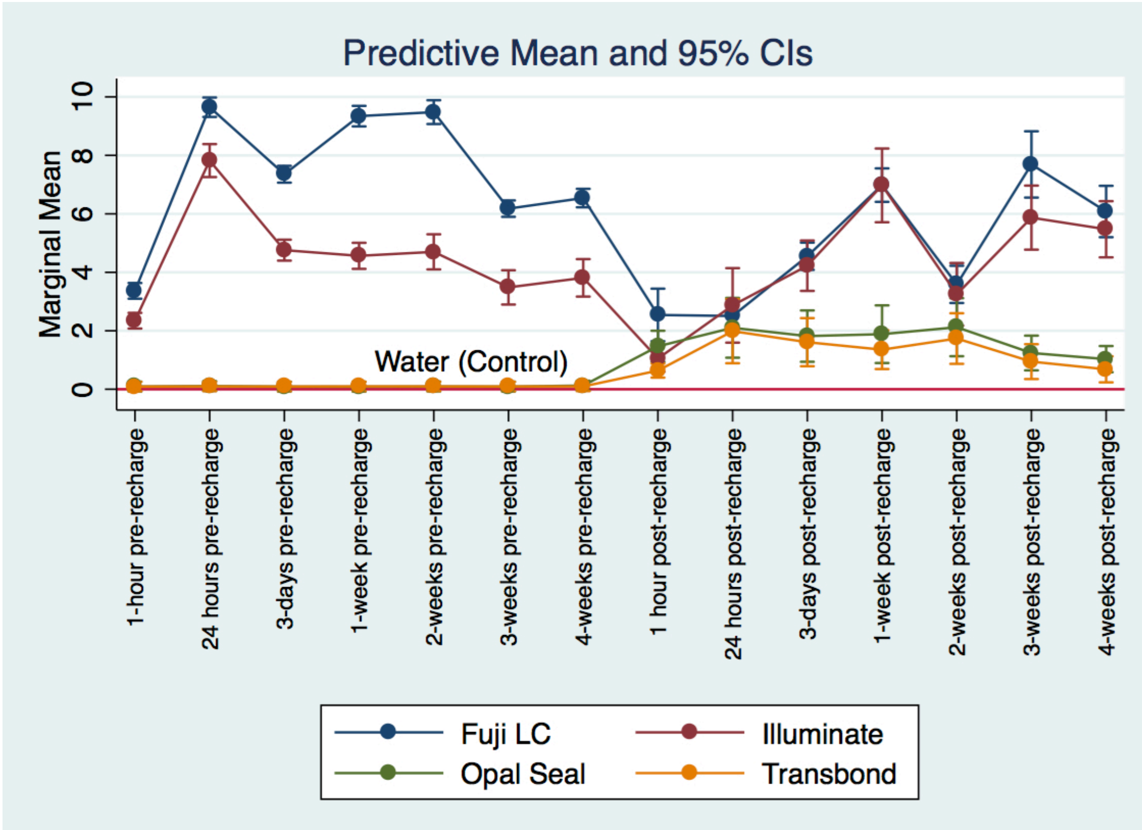


Figure 17. SEM Images at 50X

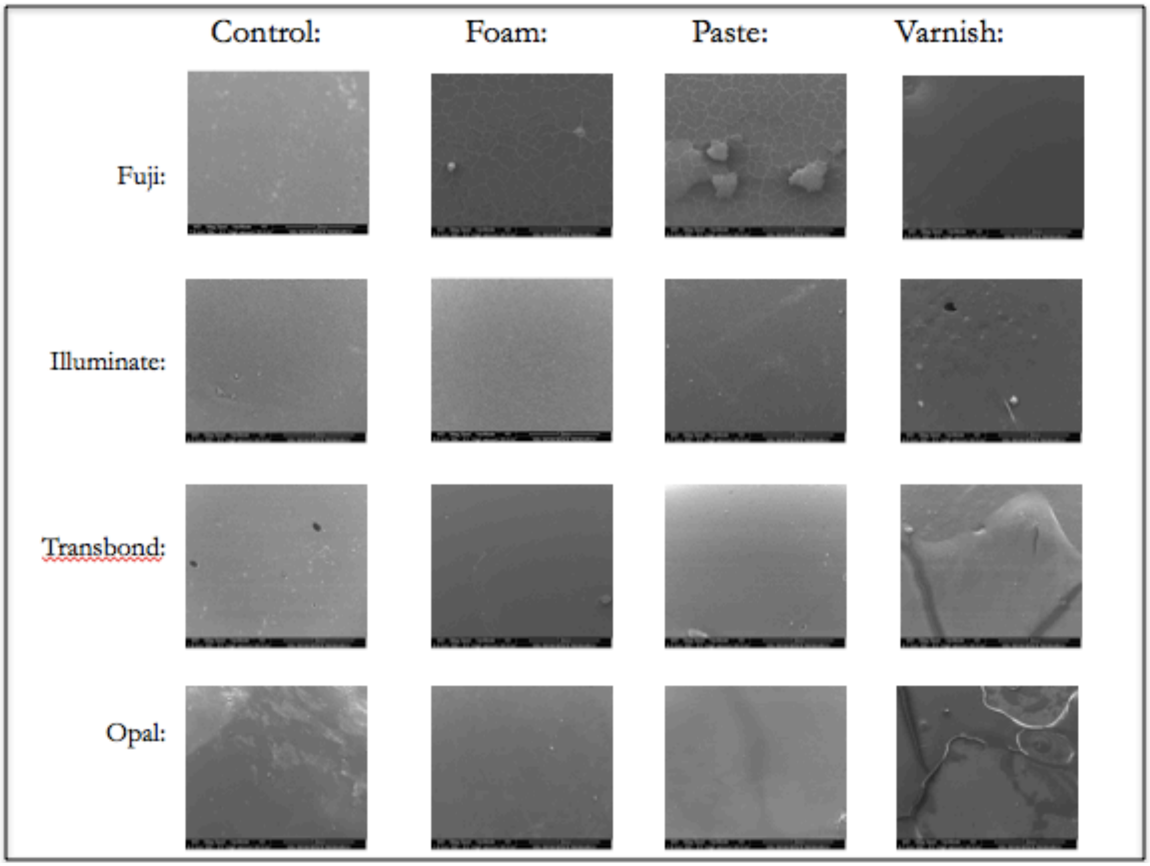
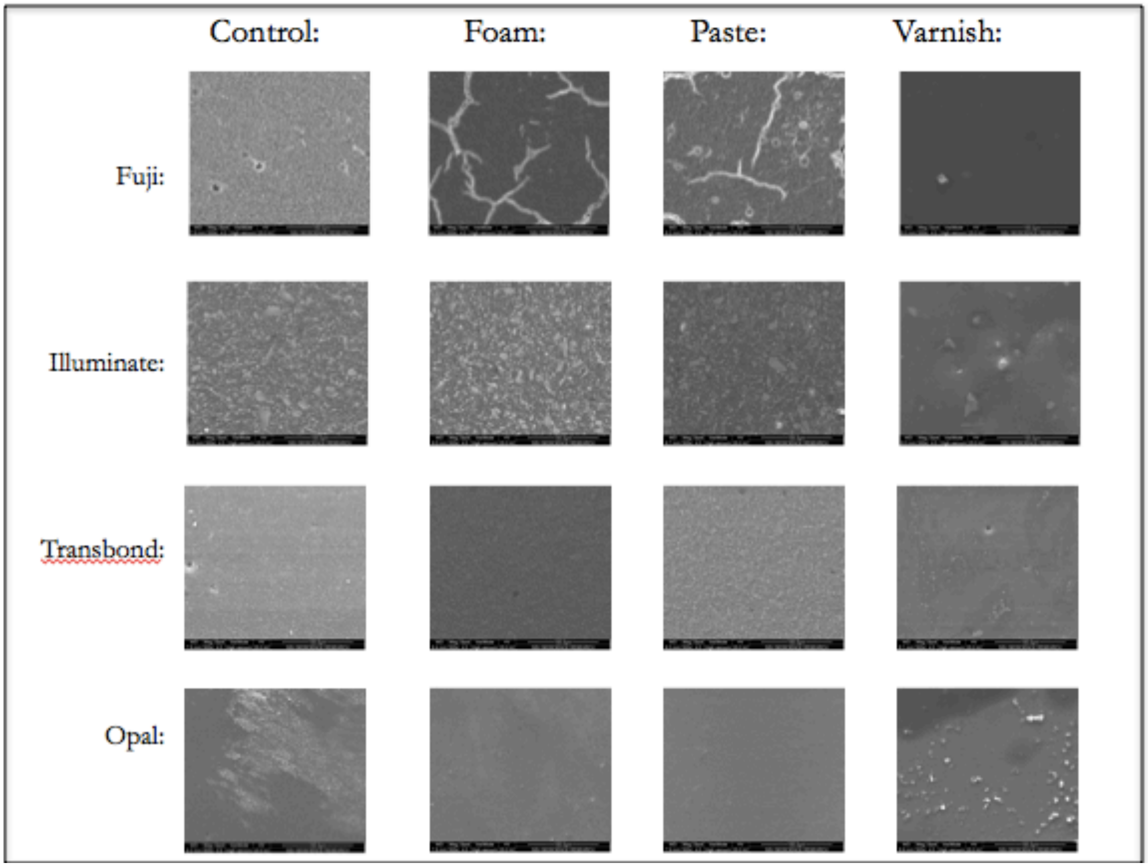


Figure 18. SEM Images at 500X



Appendix A. A Priori Power Analysis for Determination of Sample Size

A Priori Power Analysis for Determination of Sample Size

F tests - ANOVA: Fixed effects, omnibus, one-way

Analysis:	A priori: Compute required sample size	
Input:	Effect size f	= .4
	α err prob	= 0.05
	Power (1-β err prob)	= 0.95
	Number of groups	= 4
Output:	Noncentrality parameter λ	= 17.9200000
	Critical F	= 2.6886915
	Numerator df	= 3
	Denominator df	= 108
	Total sample size	= 112
	Actual power	= 0.9513019

Appendix B: Raw Data Fluoride Release and Re-release

Initial Fluoride Release (1st Four Weeks): Raw Data

Illuminate	Weight (grams)	Fluoride Release (ppm) @ 1 hour	Fluoride Release (ppm) @ 24 hours	Fluoride Release (ppm) @ 3 days	Fluoride Release (ppm) @ 1 week	Fluoride Release (ppm) @ 2 weeks	Fluoride Release (ppm) @ 3 weeks	Fluoride Release (ppm) @ 4 weeks
1	0.25	2.28	10.34	6.18	5.98	5.56	2.7	3.38
2	0.23	2.00	8.78	5.66	5.24	4.5	5.1	4.92
3	0.25	1.86	8.54	5.26	4.8	4.1	2.54	3.68
4	0.24	1.56	7.02	4.28	4.28	3.26	2.18	1.55
5	0.24	1.54	8.56	5.58	5.2	4.48	3.28	3.16
6	0.23	1.66	7.14	4.56	3.94	3.52	2.24	2.16
7	0.25	2.14	10.68	6.24	6.76	6.38	4.84	5.44
8	0.24	2.38	8.86	4.94	5.04	3.6	2.8	3.12
9	0.26	2.38	5.5	7.36	7.32	7.56	5.76	8.14
10	0.25	2.10	11.08	4.54	3.66	3.28	1.62	2.5
11	0.24	2.30	5.94	3.74	3.48	2.96	2.34	1.888
12	0.25	2.46	7.28	4.66	4.74	3.8	2.76	3.4
13	0.25	2.40	10.5	7.32	8.06	9.44	8.78	7.98
14	0.25	2.70	8.32	5.94	5.06	5.54	5.62	6.42
15	0.25	2.22	8.32	5.56	5.48	6.76	5.7	6
16	0.23	1.86	7.02	4.02	3.46	3.56	2.34	2.56
17	0.25	2.16	6.24	3.74	3.28	2.12	1.912	1.85
18	0.25	2.42	5.64	3.66	3.4	2.88	1.674	1.712
19	0.24	1.84	7.16	3.84	3.58	3.28	1.984	1.842
20	0.24	2.76	8.02	4.72	4.34	2.78	3.38	4.04
21	0.25	2.86	6.14	3.52	3.02	3.3	2.1	2.22
22	0.24	2.42	6.16	3.84	3.26	4.3	1.594	1.804
23	0.25	2.64	6.58	3.66	3.1	4.6	2.38	2.34
24	0.26	2.56	7.14	3.88	4.14	5.68	3.06	3
25	0.26	2.88	7.22	4.36	4.44	5.74	3.64	3.9
26	0.23	2.60	8.4	4.48	4.86	6.08	4.24	4.94
27	0.24	2.94	8.78	4.88	4.76	5.48	4.24	4.88
28	0.25	2.92	7.9	4.22	4.4	5.68	4.68	4.92
29	0.25	2.88	8.1	4.18	4.08	5.76	4.92	5.24
30	0.26	2.88	7.52	4.14	3.98	5.26	4.36	5.56

Initial Fluoride Release (1st Four Weeks): Raw Data

Transbond	Weight (grams)	Fluoride Release (ppm) @ 1 hour	Fluoride Release (ppm) @ 24 hours	Fluoride Release (ppm) @ 3 days	Fluoride Release (ppm) @ 1 week	Fluoride Release (ppm) @ 2 weeks	Fluoride Release (ppm) @ 3 weeks	Fluoride Release (ppm) @ 4 weeks
1	0.25	0.01	0.022	0.016	0.022	0.0282	0.0106	0.0118
2	0.24	0.01	0.021	0.012	0.0176	0.0196	0.0108	0.012
3	0.24	0.01	0.017	0.011	0.0184	0.0174	0.0106	0.0122
4	0.23	0.01	0.015	0.0102	0.0188	0.0152	0.0104	0.012
5	0.22	0.01	0.0138	0.0098	0.022	0.0146	0.0102	0.0122
6	0.23	0.01	0.0134	0.0092	0.0184	0.0142	0.0098	0.012
7	0.24	0.01	0.0124	0.009	0.0168	0.0144	0.01	0.0118
8	0.25	0.01	0.0118	0.0088	0.0162	0.014	0.0102	0.012
9	0.23	0.01	0.0116	0.0084	0.0152	0.0138	0.0102	0.0122
10	0.22	0.01	0.0112	0.0084	0.0146	0.0126	0.0098	0.0118
11	0.23	0.01	0.0108	0.0082	0.0124	0.0124	0.0106	0.013
12	0.25	0.01	0.0106	0.0078	0.0128	0.0122	0.0104	0.0124
13	0.23	0.01	0.0106	0.0076	0.013	0.0124	0.0104	0.0124
14	0.24	0.01	0.0102	0.0076	0.013	0.0124	0.0104	0.0122
15	0.25	0.01	0.0102	0.0074	0.0136	0.0124	0.0098	0.0126
16	0.24	0.01	0.0102	0.0072	0.012	0.0114	0.0106	0.014
17	0.25	0.01	0.01	0.0072	0.0122	0.0114	0.0106	0.0142
18	0.26	0.01	0.01	0.0072	0.0122	0.0116	0.0106	0.0138
19	0.23	0.01	0.0098	0.0072	0.012	0.0116	0.0106	0.014
20	0.24	0.01	0.0098	0.0072	0.0122	0.0114	0.0106	0.0102
21	0.24	0.01	0.0098	0.0072	0.0118	0.0116	0.0104	0.01
22	0.23	0.01	0.0096	0.0072	0.0118	0.0116	0.0106	0.0142
23	0.24	0.01	0.0096	0.0072	0.0118	0.0118	0.0108	0.014
24	0.25	0.01	0.0094	0.0072	0.0118	0.0118	0.0104	0.014
25	0.22	0.01	0.0094	0.007	0.0118	0.012	0.0104	0.0152
26	0.24	0.01	0.0094	0.007	0.0104	0.0104	0.0112	0.0104
27	0.25	0.01	0.0092	0.0068	0.0106	0.0106	0.011	0.011
28	0.26	0.01	0.009	0.0068	0.011	0.0102	0.0108	0.0102
29	0.25	0.01	0.009	0.0066	0.0112	0.0098	0.0104	0.0132
30	0.26	0.01	0.0088	0.0066	0.0116	0.0096	0.0102	0.0134

Initial Fluoride Release (1st Four Weeks): Raw Data

Opal	Weight (grams)	Fluoride Release (ppm) @ 1 hour	Fluoride Release (ppm) @ 24 hours	Fluoride Release (ppm) @ 3 days	Fluoride Release (ppm) @ 1 week	Fluoride Release (ppm) @ 2 weeks	Fluoride Release (ppm) @ 3 weeks	Fluoride Release (ppm) @ 4 weeks
1	0.24	0.07	0.0794	0.046	0.0192	0.0284	0.0278	0.0562
2	0.24	0.05	0.075	0.039	0.0232	0.0288	0.0278	0.0556
3	0.22	0.04	0.0824	0.043	0.0258	0.0308	0.0288	0.0584
4	0.24	0.04	0.049	0.035	0.0254	0.0308	0.0292	0.0582
5	0.23	0.04	0.0378	0.03	0.024	0.0288	0.0284	0.0564
6	0.23	0.03	0.0388	0.0284	0.0236	0.026	0.0278	0.0546
7	0.24	0.03	0.046	0.0314	0.0238	0.0262	0.0274	0.054
8	0.26	0.03	0.0424	0.03	0.024	0.0274	0.0274	0.055
9	0.23	0.04	0.0416	0.0284	0.0246	0.0282	0.0276	0.058
10	0.23	0.04	0.046	0.0286	0.0254	0.0284	0.0282	0.0586
11	0.25	0.03	0.0542	0.0298	0.026	0.0308	0.028	0.0572
12	0.24	0.03	0.0354	0.0266	0.0262	0.0298	0.0276	0.0556
13	0.22	0.03	0.0462	0.0278	0.0274	0.0308	0.0278	0.0578
14	0.25	0.03	0.045	0.0284	0.0276	0.0302	0.028	0.0586
15	0.24	0.02	0.0348	0.0264	0.0234	0.0264	0.0282	0.0584
16	0.25	0.02	0.0294	0.0246	0.0226	0.0322	0.032	0.0572
17	0.26	0.02	0.0302	0.0236	0.0242	0.0314	0.0294	0.0554
18	0.24	0.02	0.0296	0.0234	0.0254	0.0312	0.0292	0.0596
19	0.23	0.02	0.0306	0.0246	0.0258	0.0302	0.0284	0.0554
20	0.23	0.02	0.0312	0.0244	0.025	0.0312	0.0278	0.0552
21	0.24	0.03	0.0432	0.027	0.032	0.0466	0.0328	0.0804
22	0.23	0.03	0.0456	0.0276	0.0316	0.0406	0.0322	0.0654
23	0.24	0.03	0.0582	0.0282	0.0312	0.0398	0.0324	0.0686
24	0.24	0.02	0.0396	0.0266	0.027	0.035	0.032	0.0702
25	0.22	0.03	0.0784	0.0296	0.0292	0.0328	0.0324	0.0642
26	0.21	0.04	0.0852	0.035	0.0332	0.0694	0.0378	0.1124
27	0.22	0.03	0.0534	0.0316	0.0346	0.0506	0.0348	0.0856
28	0.22	0.02	0.039	0.0268	0.0274	0.0386	0.0328	0.0752
29	0.24	0.02	0.0354	0.0254	0.026	0.0372	0.0314	0.069
30	0.23	0.05	0.1118	0.0412	0.0412	0.052	0.032	0.0922

Initial Fluoride Release (1st Four Weeks): Raw Data

Fuji	Weight (grams)	Fluoride Release (ppm) @ 1 hour	Fluoride Release (ppm) @ 24 hours	Fluoride Release (ppm) @ 3 days	Fluoride Release (ppm) @ 1 week	Fluoride Release (ppm) @ 2 weeks	Fluoride Release (ppm) @ 3 weeks	Fluoride Release (ppm) @ 4 weeks
1	0.24	4.58	11.22	8.08	10.38	10.2	6.8	8.04
2	0.25	3.28	9.32	6.9	8.62	9.28	5.96	6.8
3	0.23	2.84	10.08	6.88	9.32	9.3	5.84	6.74
4	0.24	2.64	9.36	7.02	8.42	9.46	5.84	6.84
5	0.23	3.02	9.52	7.1	8.14	9.34	5.92	6.76
6	0.23	2.92	8.98	6.76	8.3	8.5	5.8	6.62
7	0.25	3.58	9.52	7.14	9.36	9.82	5.52	6.52
8	0.23	2.98	10	7.2	9.1	9.82	5.86	6.84
9	0.23	4.04	10.86	8.42	10.8	12.02	6.94	7.72
10	0.23	4.30	10.3	7.92	10.08	9.62	6.76	7.94
11	0.24	3.44	9.84	7.78	9.96	9.34	6.66	3.9
12	0.23	3.02	9.76	7.22	9.48	9.34	6.28	6.18
13	0.23	2.86	11.46	7.56	9.16	10.8	6.2	6.76
14	0.23	4.06	9.44	9.02	11.12	9.28	7.32	7.66
15	0.23	3.20	9.92	6.74	8.44	8.68	6.26	6.94
16	0.23	3.58	10.12	7.56	9.76	10.62	7.34	7.02
17	0.23	3.64	9.4	7.4	9.68	8.16	6.54	6.5
18	0.24	3.70	9.6	7.84	10.08	10.28	6.68	6.62
19	0.24	3.50	9.32	6.68	8.88	7.92	5.7	6.1
20	0.23	3.36	9.52	7.28	9.52	8.86	6.34	6.8
21	0.25	3.44	10	7.22	9.24	9.24	6.04	5.92
22	0.23	3.56	10.72	7.1	9.24	9.38	5.96	6.68
23	0.23	4.22	10.04	7.6	10.72	10.58	6.58	7.68
24	0.23	4.28	9.4	8.42	10.5	10.94	6.94	7.16
25	0.24	4.58	8.8	7.34	9.24	10.28	6.5	6.72
26	0.23	2.82	9.44	7.2	8.7	8.18	5.12	5.8
27	0.23	2.96	8.88	6.76	8.38	8.5	5.68	5.78
28	0.23	3.14	9.1	7.68	9.4	9.54	5.96	6.14
29	0.23	3.72	9.4	8.56	9.88	10.9	6.96	6.46
30	0.24	3.82	10.2	8.34	10.46	10.28	7.16	6.66

Initial Fluoride Release (1st Four Weeks): Raw Data

Control of Deionized H2O	Fluoride Release (ppm) @ 1 hour	Fluoride Release (ppm) @ 24 hours	Fluoride Release (ppm) @ 3 days	Fluoride Release (ppm) @ 1 week	Fluoride Release (ppm) @ 2 weeks	Fluoride Release (ppm) @ 3 weeks	Fluoride Release (ppm) @ 4 weeks
1	0.02	0.0274	0.0242	0.0094	0.0274	0.01	0.0106
2	0.02	0.0214	0.0178	0.0098	0.0192	0.0104	0.0102
3	0.01	0.0192	0.0152	0.01	0.0158	0.0108	0.01
4	0.01	0.018	0.0132	0.0102	0.0144	0.011	0.01
5	0.01	0.0158	0.0122	0.0104	0.0134	0.0112	0.0098
6	0.01	0.0148	0.0114	0.0106	0.0124	0.0114	0.0116
7	0.01	0.014	0.011	0.0112	0.0116	0.0124	0.0116
8	0.01	0.0136	0.0106	0.0118	0.011	0.0138	0.0114
9	0.01	0.0128	0.0104	0.013	0.0104	0.0148	0.0108
10	0.01	0.0122	0.0112	0.0158	0.0104	0.0178	0.0106

Fluoride Re-Release (2nd Four Weeks): Raw Data

Illuminate	Weight (grams)	Fluoride Release (ppm) @ 1 hour	Fluoride Release (ppm) @ 24 hours	Fluoride Release (ppm) @ 3 days	Fluoride Release (ppm) @ 1 week	Fluoride Release (ppm) @ 2 weeks	Fluoride Release (ppm) @ 3 weeks	Fluoride Release (ppm) @ 4 weeks
Varnish1	0.24	0.314	3.76	3.32	4.28	5.42	3.84	3.76
Foam9	0.26	2.6	1.17	2.16	4.72	11.02	9.08	8.86
Varnish7	0.26	1.188	9.98	9.32	8.04	9.62	5.04	4.88
Foam10	0.24	2.16	0.62	1.028	2.34	5.56	4.18	3.98
Varnish8	0.25	0.856	9.28	9.54	7.98	6.96	3.8	4.1
Foam2	0.25	0.366	0.46	0.824	1.634	3.64	3.46	4.12
Paste1	0.25	0.248	0.706	2.3	5.36	10.9	9.98	9.52
Paste7	0.26	0.1102	0.336	1	2.7	5.5	5.88	6.02
Varnish6	0.28	0.708	6.34	6.94	8.78	12.52	10.88	7.86
Paste4	0.26	0.444	0.344	0.814	1.89	3.66	3.42	3.4
Foam1	0.24	0.466	0.38	0.878	1.622	3.46	3.34	3.28
Foam3	0.25	1.59	0.68	1.474	3.2	6.16	5.74	5.8
Foam7	0.25	3	1.706	3.66	8.34	16.36	14.48	12.6
Varnish5	0.26	0.784	8.1	7.58	6.28	12.34	8.8	5.76
Varnish9	0.26	1.222	9.86	7.66	6.04	5.7	4.14	4.1
Paste9	0.24	0.0972	0.284	0.832	2.12	4.26	3.82	3.92
Foam8	0.25	1.912	0.636	1.302	1.45	3.38	4.08	3.28
Paste8	0.25	0.1482	0.224	0.586	1.646	2.6	2.54	2.34
Foam5	0.24	3.12	0.912	1.956	4.12	9.12	7.92	6.96
Varnish10	0.25	1.116	10.96	9.86	8.6	6.66	3.5	3.28
Paste3	0.26	0.426	0.266	0.698	1.616	3.42	3.38	3.32
Paste6	0.25	0.242	0.206	0.714	1.568	3.48	2.9	3.72
Varnish3	0.26	0.498	4.78	4.12	3.1	3.18	2.64	2.58
Paste2	0.25	0.34	0.452	1.352	2.96	5.94	5.3	5.04
Varnish4	0.27	0.674	5.68	5.68	5.74	8	7.66	3.82
Paste10	0.23	0.0772	0.746	2.14	4.24	9.06	7.44	7.46
Varnish2	0.25	0.43	4.72	4.06	3.44	5	4.78	5.96
Foam4	0.24	2.04	0.43	0.832	2.08	4.36	3.56	3.82
Foam6	0.25	4.3	1.092	2.52	5.34	11.66	11.54	11.86
Paste5	0.25	0.256	1.17	2.52	5.78	10.5	9.22	9

Fluoride Re-Release (2nd Four Weeks): Raw Data

Transbond	Weight (grams)	Fluoride Release (ppm) @ 1 hour	Fluoride Release (ppm) @ 24 hours	Fluoride Release (ppm) @ 3 days	Fluoride Release (ppm) @ 1 week	Fluoride Release (ppm) @ 2 weeks	Fluoride Release (ppm) @ 3 weeks	Fluoride Release (ppm) @ 4 weeks
Foam1	0.25	0.386	0.0244	0.0316	0.0332	0.03	0.0318	0.0362
Varnish3	0.26	0.894	3.62	4.14	4.02	5.14	8.08	6.02
Paste6	0.25	0.1004	0.0242	0.0292	0.0326	0.0296	0.0304	0.0352
Varnish9	0.24	0.872	6.9	6.98	5.9	2.18	2.76	1.45
Varnish10	0.25	0.936	7.84	8.04	9.08	6.38	4.5	3.92
Paste5	0.24	0.0448	0.0162	0.0242	0.0244	0.0232	0.0256	0.028
Foam2	0.23	0.0968	0.0224	0.0298	0.0322	0.0292	0.0312	0.0348
Foam10	0.24	0.23	0.0262	0.0336	0.0346	0.0308	0.0332	0.0376
Varnish4	0.23	0.642	3.46	3.42	2.12	2.62	1.814	0.854
Foam4	0.24	2.74	0.0258	0.0288	0.0312	0.0296	0.0306	0.0336
Paste8	0.24	0.0282	0.0198	0.0268	0.0278	0.0262	0.0272	0.0308
Foam6	0.26	0.167	0.0402	0.054	0.0456	0.0586	0.0542	0.0542
Foam7	0.22	1.798	0.0376	0.0432	0.0414	0.0442	0.0434	0.0474
Paste9	0.24	0.0266	0.018	0.0264	0.027	0.0256	0.0266	0.03
Paste7	0.25	0.1192	0.0212	0.028	0.0298	0.0278	0.0288	0.0328
Varnish1	0.24	0.502	2.2	3.08	2.64	2.7	0.654	1.204
Paste3	0.24	0.1608	0.0164	0.0244	0.0252	0.0232	0.0254	0.0276
Foam9	0.26	0.082	0.0282	0.0352	0.0354	0.0322	0.0338	0.0382
Foam3	0.24	0.872	0.025	0.029	0.0318	0.0294	0.0308	0.0342
Paste1	0.24	0.0686	0.0168	0.0246	0.0258	0.0248	0.0272	0.0294
Foam5	0.25	0.234	0.0246	0.0284	0.0302	0.029	0.03	0.033
Varnish5	0.24	1.042	3.96	5.2	3.3	2.22	1.088	0.656
Varnish7	0.26	0.728	5.5	4.52	4.16	5.04	1.108	0.614
Varnish8	0.26	0.818	7.02	5.74	3.92	1.83	0.544	0.246
Paste4	0.23	0.0834	0.0164	0.034	0.025	0.0236	0.0254	0.028
Varnish2	0.25	0.988	2.96	3.46	4.32	3.7	2.08	0.956
Paste10	0.25	0.0272	0.0172	0.0254	0.0264	0.0254	0.0266	0.03
Varnish6	0.29	1.14	13.12	4.3	5.68	5.66	2.56	1.312
Foam8	0.26	0.388	0.0316	0.038	0.0368	0.0358	0.0344	0.0394
Paste2	0.25	0.412	0.0166	0.0246	0.0256	0.0238	0.026	0.028

Fluoride Re-Release (2nd Four Weeks): Raw Data

Opal	Weight (grams)	Fluoride Release (ppm) @ 1 hour	Fluoride Release (ppm) @ 24 hours	Fluoride Release (ppm) @ 3 days	Fluoride Release (ppm) @ 1 week	Fluoride Release (ppm) @ 2 weeks	Fluoride Release (ppm) @ 3 weeks	Fluoride Release (ppm) @ 4 weeks
Paste2	0.25	0.07	0.0794	0.046	0.0192	0.0284	0.0278	0.0562
Foam9	0.24	0.05	0.075	0.039	0.0232	0.0288	0.0278	0.0556
Varnish1	0.24	0.04	0.0824	0.043	0.0258	0.0308	0.0288	0.0584
Paste6	0.25	0.04	0.049	0.035	0.0254	0.0308	0.0292	0.0582
Foam3	0.24	0.04	0.0378	0.03	0.024	0.0288	0.0284	0.0564
Foam1	0.23	0.03	0.0388	0.0284	0.0236	0.026	0.0278	0.0546
Paste4	0.24	0.03	0.046	0.0314	0.0238	0.0262	0.0274	0.054
Foam7	0.25	0.03	0.0424	0.03	0.024	0.0274	0.0274	0.055
Varnish5	0.25	0.04	0.0416	0.0284	0.0246	0.0282	0.0276	0.058
Varnish9	0.25	0.04	0.046	0.0286	0.0254	0.0284	0.0282	0.0586
Varnish6	0.26	0.03	0.0542	0.0298	0.026	0.0308	0.028	0.0572
Varnish4	0.26	0.03	0.0354	0.0266	0.0262	0.0298	0.0276	0.0556
Paste8	0.24	0.03	0.0462	0.0278	0.0274	0.0308	0.0278	0.0578
Varnish3	0.25	0.03	0.045	0.0284	0.0276	0.0302	0.028	0.0586
Foam4	0.26	0.02	0.0348	0.0264	0.0234	0.0264	0.0282	0.0584
Varnish7	0.28	0.02	0.0294	0.0246	0.0226	0.0322	0.032	0.0572
Paste5	0.26	0.02	0.0302	0.0236	0.0242	0.0314	0.0294	0.0554
Paste9	0.25	0.02	0.0296	0.0234	0.0254	0.0312	0.0292	0.0596
Paste7	0.23	0.02	0.0306	0.0246	0.0258	0.0302	0.0284	0.0554
Paste10	0.24	0.02	0.0312	0.0244	0.025	0.0312	0.0278	0.0552
Foam6	0.25	0.03	0.0432	0.027	0.032	0.0466	0.0328	0.0804
Foam10	0.22	0.03	0.0456	0.0276	0.0316	0.0406	0.0322	0.0654
Paste3	0.24	0.03	0.0582	0.0282	0.0312	0.0398	0.0324	0.0686
Foam2	0.25	0.02	0.0396	0.0266	0.027	0.035	0.032	0.0702
Varnish10	0.23	0.03	0.0784	0.0296	0.0292	0.0328	0.0324	0.0642
Varnish8	0.23	0.04	0.0852	0.035	0.0332	0.0694	0.0378	0.1124
Foam8	0.24	0.03	0.0534	0.0316	0.0346	0.0506	0.0348	0.0856
Varnish2	0.23	0.02	0.039	0.0268	0.0274	0.0386	0.0328	0.0752
Foam5	0.23	0.02	0.0354	0.0254	0.026	0.0372	0.0314	0.069
Paste1	0.25	0.05	0.1118	0.0412	0.0412	0.052	0.032	0.0922

Fluoride Re-Release (2nd Four Weeks): Raw Data

Fuji	Weight (grams)	Fluoride Release (ppm) @ 1 hour	Fluoride Release (ppm) @ 24 hours	Fluoride Release (ppm) @ 3 days	Fluoride Release (ppm) @ 1 week	Fluoride Release (ppm) @ 2 weeks	Fluoride Release (ppm) @ 3 weeks	Fluoride Release (ppm) @ 4 weeks
Paste8	0.23	1.158	1.606	2.2	3.74	6.2	6.4	5.42
Varnish10	0.26	1.168	4.82	7.98	8	12.04	15.64	12.1
Foam4	0.24	7.38	2.46	3.04	4.54	6.84	6.82	5.38
Varnish8	0.26	0.818	3.18	5.28	5.78	9.32	8.8	5.96
Foam5	0.24	6.94	2.18	2.86	4.34	6.8	7.06	5.06
Varnish1	0.26	3.66	6.6	6.24	6.58	8.94	13.52	12.56
Varnish6	0.27	1.906	8.4	8.36	7.66	10.04	20.4	15.12
Foam6	0.24	5.52	1.692	3.22	4.14	5.76	6.58	5.1
Varnish3	0.25	0.792	3.42	5.68	5.22	7.44	6.5	4.9
Paste4	0.26	0.782	1.354	2	3.46	5.82	5.9	4.88
Foam8	0.25	6.56	2.06	2.88	4.12	5.7	7	5.42
Paste1	0.24	0.78	1.308	2.12	3.42	5.58	5.96	5.24
Foam7	0.24	5.7	2.2	2.94	4.28	6.66	6.56	5.04
Varnish9	0.26	0.976	3.86	5.72	7.28	10.8	6.48	5.48
Paste7	0.25	0.888	1.4	2.06	3.42	6.24	6.24	5.18
Varnish5	0.26	1.552	3.76	5.38	5.62	8.88	8.5	6.72
Foam2	0.24	4	1.666	2.54	4.14	6.1	6.78	5.12
Foam9	0.24	7.48	2.06	2.98	4.26	6.9	7.06	5.44
Paste6	0.25	0.922	1.17	1.856	3.06	5.5	5.84	4.68
Foam10	0.24	5.44	1.906	3.04	4.28	6.42	6.78	5.42
Paste5	0.24	0.958	1.266	2.04	3.28	6.04	6	4.86
Varnish7	0.26	0.822	3.54	4.46	3.72	7.1	8.94	6.34
Varnish4	0.25	1.684	4.02	6.02	5.86	7.8	8.2	6.16
Paste9	0.24	0.972	1.496	2.18	3.8	6.52	6.24	5.46
Foam1	0.25	3.74	1.73	2.84	4.14	4.82	6.52	5.24
Varnish2	0.25	2.02	4.68	7.2	7.86	9.22	9.24	7.64
Paste2	0.24	0.616	1.202	1.906	3.22	5.46	5.72	4.8
Foam3	0.25	3.36	1.554	2.48	4.14	6.46	6.52	5.2
Paste10	0.24	0.968	1.41	2.24	3.76	6.24	6.56	5.3
Paste3	0.26	0.772	1.284	1.97	3.46	5.94	6.04	5.26

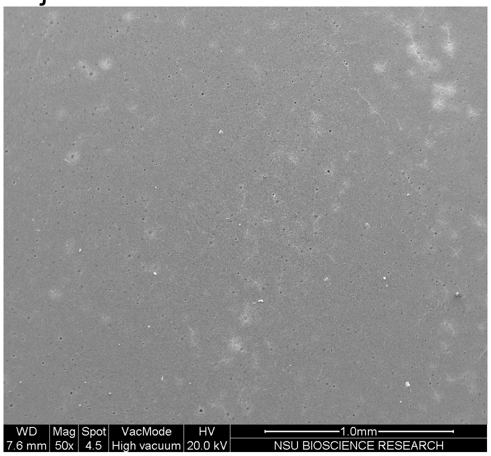
Fluoride Release (2nd Four Weeks): Raw Data

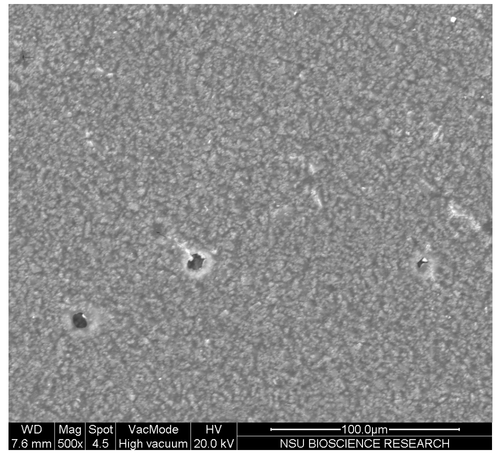
Control of Deionized H2O	Fluoride Release (ppm) @ 1 hour	Fluoride Release (ppm) @ 24 hours	Fluoride Release (ppm) @ 3 days	Fluoride Release (ppm) @ 1 week	Fluoride Release (ppm) @ 2 weeks	Fluoride Release (ppm) @ 3 weeks	Fluoride Release (ppm) @ 4 weeks
1	0.0102	0.0142	0.0276	0.0212	0.0186	0.0206	0.0212
2	0.0116	0.0142	0.0256	0.0206	0.0182	0.0202	0.0206
3	0.0104	0.014	0.0238	0.0202	0.0182	0.0198	0.0204
4	0.0118	0.0142	0.0224	0.0198	0.0178	0.0196	0.02
5	0.012	0.0138	0.0222	0.0196	0.0178	0.0192	0.0198
6	0.0164	0.0166	0.0214	0.0252	0.023	0.0252	0.026
7	0.0144	0.0162	0.021	0.024	0.0214	0.0234	0.0242
8	0.0138	0.0158	0.02	0.0234	0.0206	0.0224	0.0228
9	0.0134	0.015	0.0192	0.0224	0.0198	0.0216	0.0222
10	0.0136	0.0144	0.0186	0.0218	0.0192	0.021	0.0218

Appendix C: Raw Data SEM Images

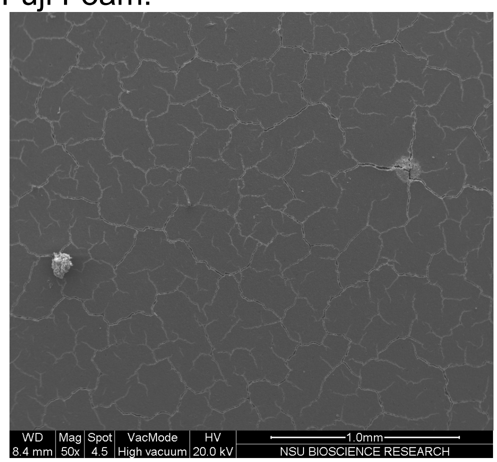
50X | 500X

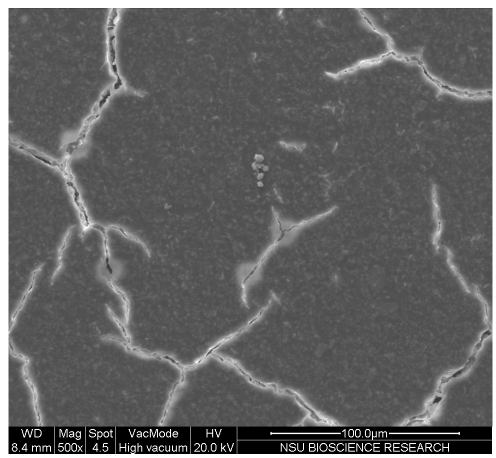
Fuji Control:



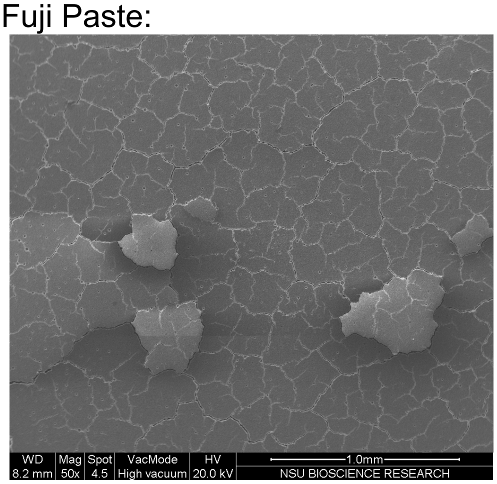


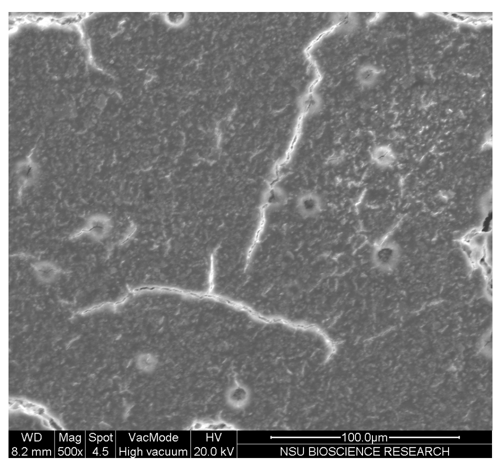
Fuji Foam:





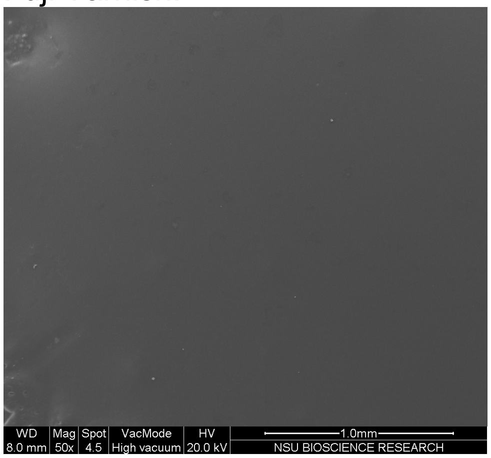
Fuji Paste:

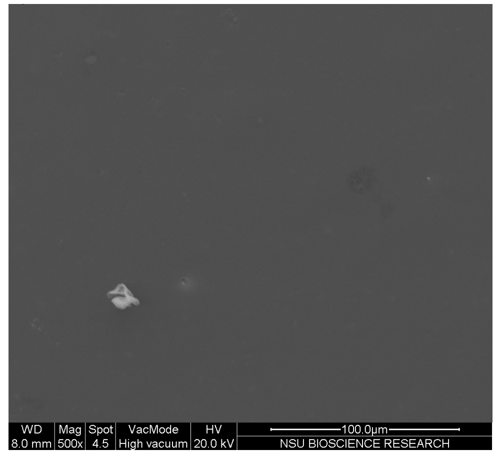




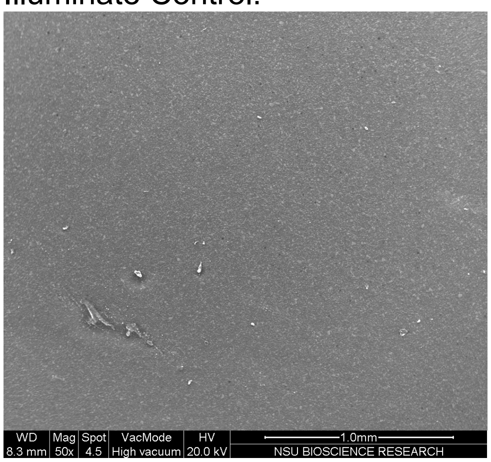
50X 500X

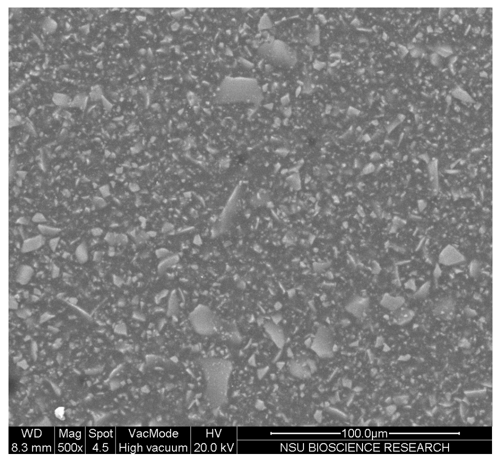
Fuji Varnish:



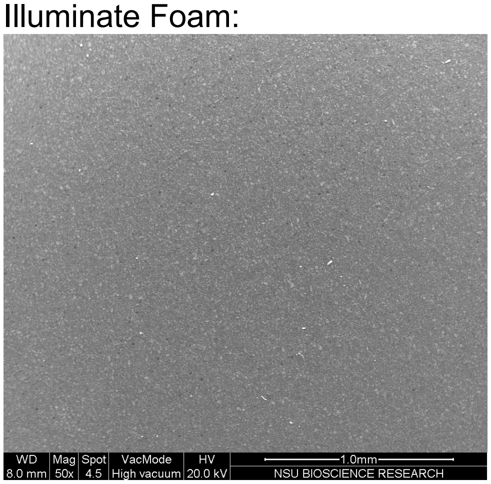


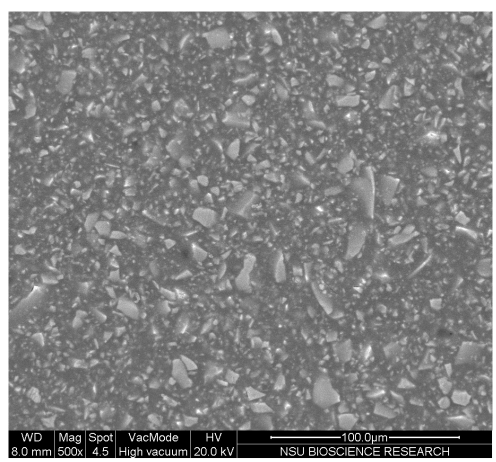
Illuminate Control:





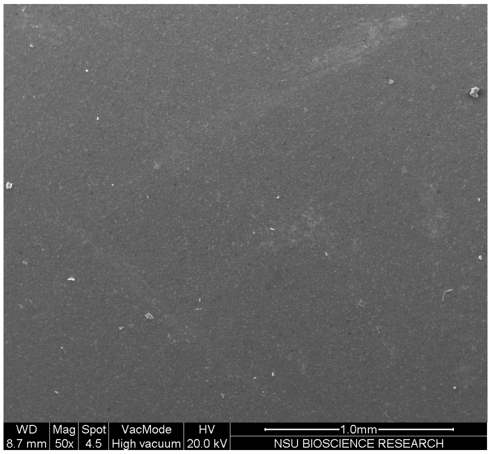
Illuminate Foam:

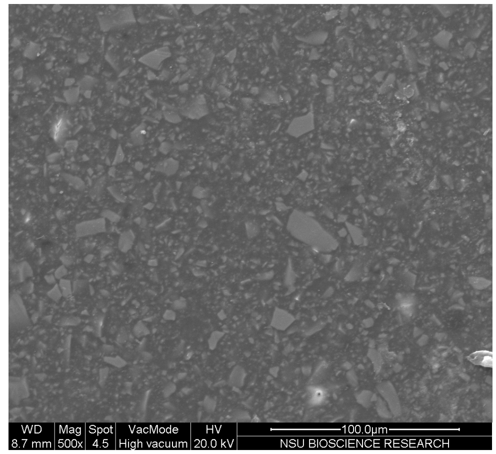




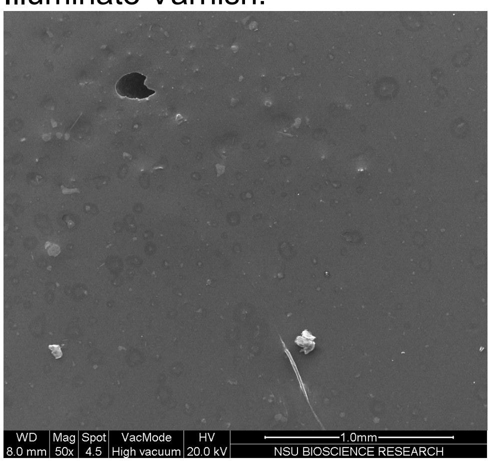
50X 500X

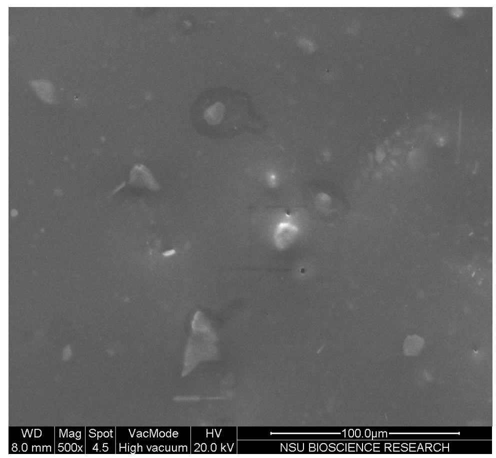
Illuminate Paste:



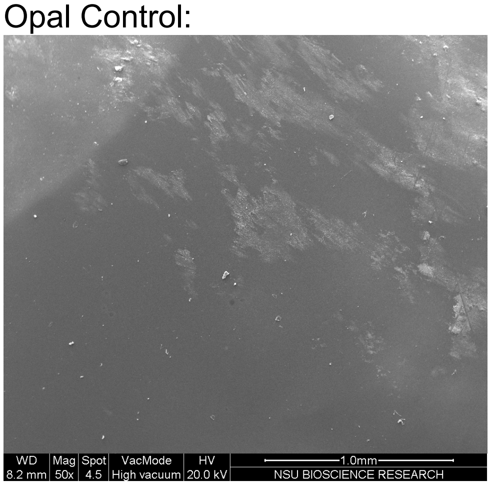


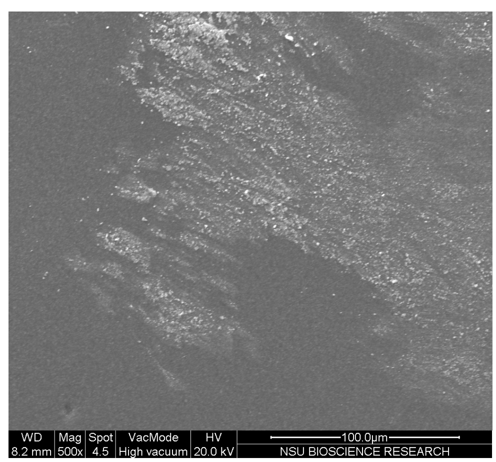
Illuminate Varnish:





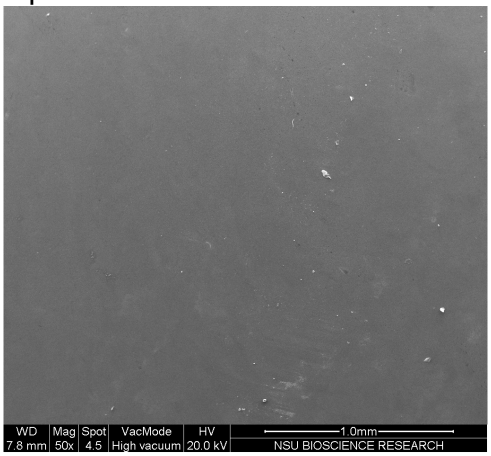
Opal Control:

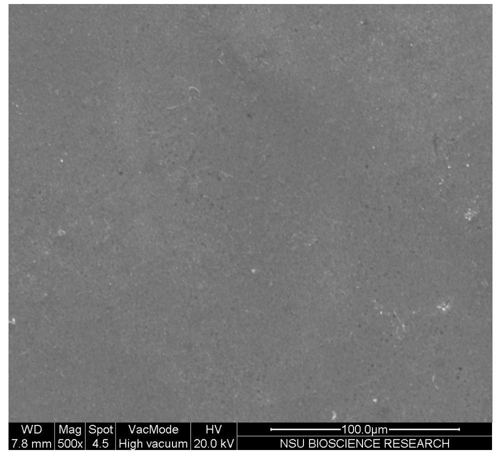




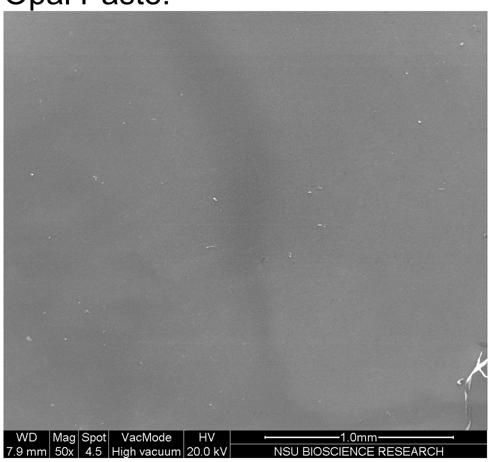
50X 500X

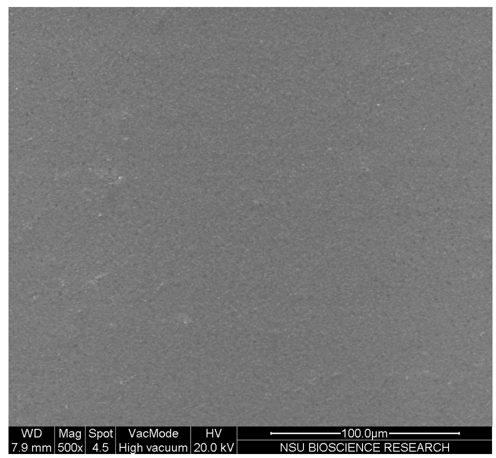
Opal Foam:



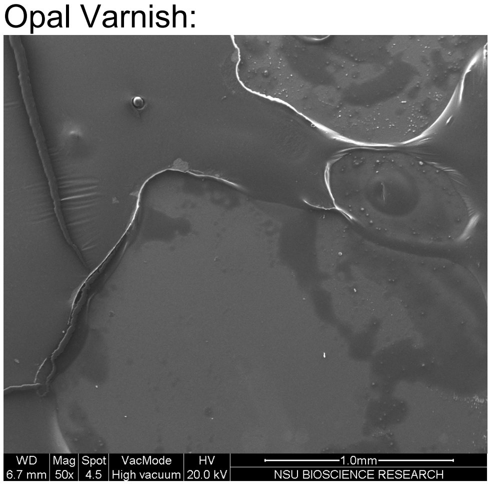


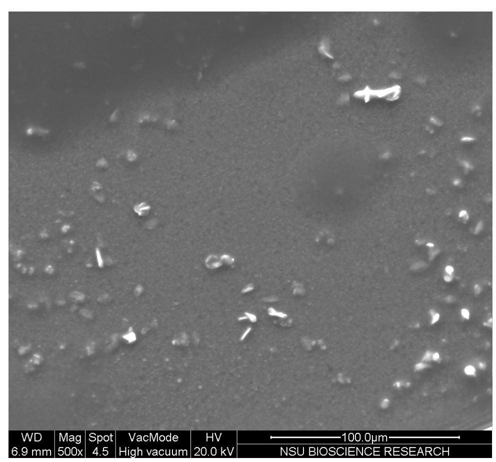
Opal Paste:





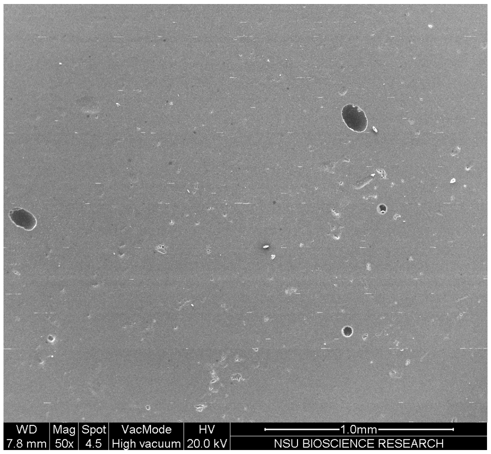
Opal Varnish:

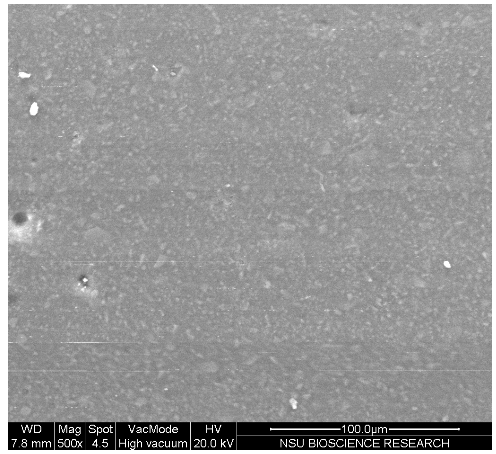




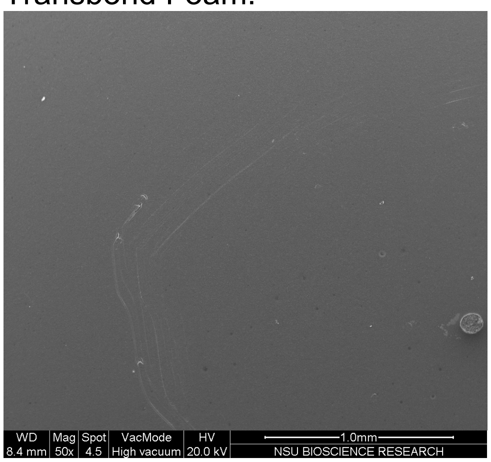
50X 500X

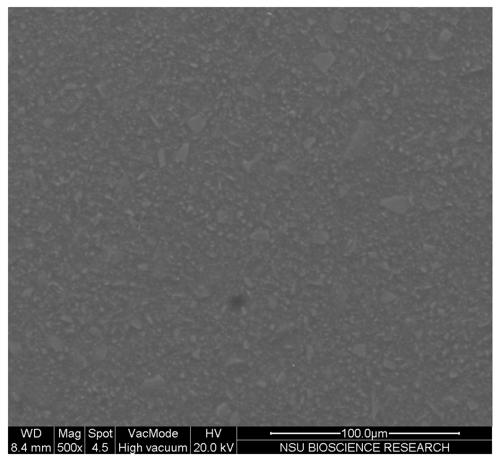
Transbond Control:



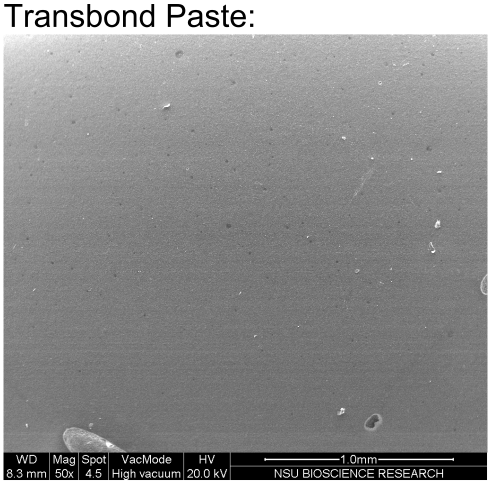


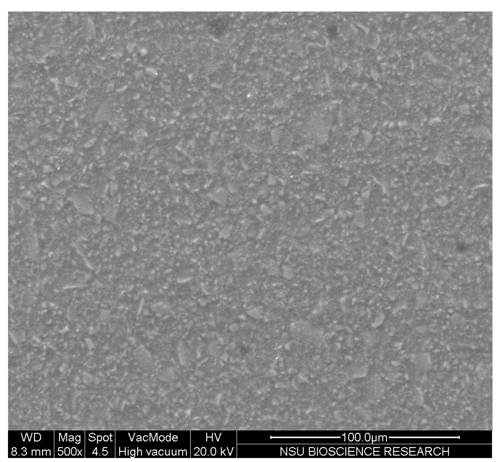
Transbond Foam:





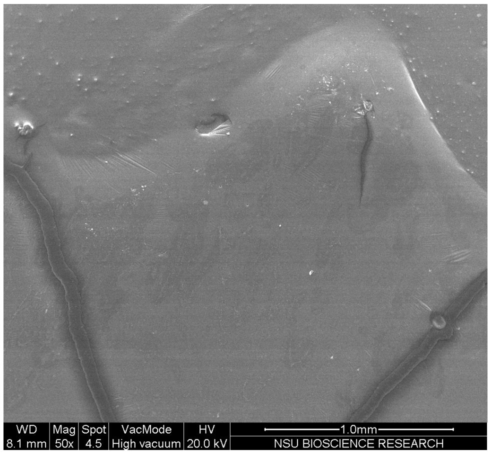
Transbond Paste:

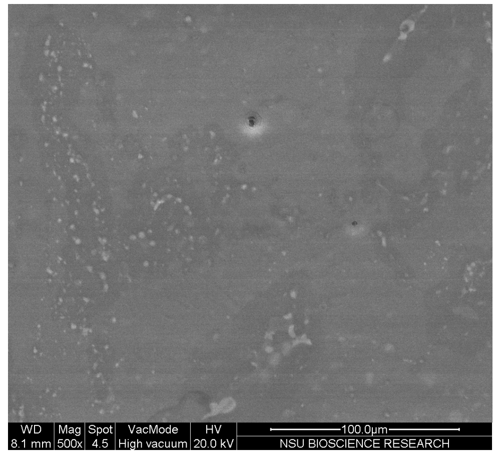




50X 500X

Transbond Varnish:





Bibliography

1. Ogaard B, Bishara S, Suschner H. Enamel Effects during bonding-debonding and treatment with fixed appliances. Quintessence 2004:19-46.
2. Zachrisson BU, Zachrisson S. Caries incidence and oral hygiene during orthodontic treatment. Scandinavian Journal of Dental Research 1971;79(6):394-401.
3. Zachrisson BU, Zachrisson S. Caries incidence and orthodontic treatment with fixed appliances. Scandinavian Journal of Dental Research 1971;79(3):183-92.
4. Tillery TJ, Hembree JH, Jr., Weber FN. Preventing enamel decalcification during orthodontic treatment. American Journal of Orthodontics 1976;70(4):435-9.
5. Ceen RF, Gwinnett AJ. Microscopic evaluation of the thickness of sealants used in orthodontic bonding. American Journal of Orthodontics 1980;78(6):623-9.
6. Diedrich P. Enamel alterations from bracket bonding and debonding: a study with the scanning electron microscope. American Journal of Orthodontics 1981;79(5):500-22.
7. Gorelick L, Geiger AM, Gwinnett AJ. Incidence of white spot formation after bonding and banding. American Journal of Orthodontics 1982;81(2):93-8.
8. Ogaard B, Rolla G, Arends J. Orthodontic appliances and enamel demineralization. Part 1. Lesion development. American Journal of Orthodontics and Dentofacial Orthopedics 1988;94(1):68-73.
9. Tell RT, Sydiskis RJ, Isaacs RD, Davidson WM. Long-term cytotoxicity of orthodontic direct-bonding adhesives. American Journal of Orthodontics and Dentofacial Orthopedics 1988;93(5):419-22.
10. Koulourides T, Keller SE, Manson-Hing L, Lilley V. Enhancement of fluoride effectiveness by experimental cariogenic priming of human enamel. Caries Research 1980;14(1):32-9.
11. Justus R, Cubero T, Ondarza R, Morales F. A new technique with sodium hypochlorite to increase bracket shear bond strength of fluoride-releasing resin-modified glass ionomer cements: comparing shear bond strength of two adhesive systems with enamel surface deproteinization before etching. Seminars in Orthodontics 2010;16(1):66-75.
12. Ahn SJ, Lee SJ, Lee DY, Lim BS. Effects of different fluoride recharging protocols on fluoride ion release from various orthodontic adhesives. Journal of Dentistry 2010;39(3):196-201.
13. dos Santos RL, Pithon MM, Vaitsman DS, et al. Long-term fluoride release from resin-reinforced orthodontic cements following recharge with fluoride solution. Brazilian Dental Journal 2010;21(2):98-103.
14. Itota T, Carrick TE, Yoshiyama M, McCabe JF. Fluoride release and recharge in giomer, compomer and resin composite. Dental Materials 2004;20(9):789-95.

15. McKay FS. Mottled enamel: the prevention of its further production through a change of water supply at Oakley, Ida. J Am Dent Assoc 1933;20(7):1137-49.
16. McClure FJ. Water fluoridation: the search and the victory. Bethesda, Maryland: National Institute of Dental Research;1970.
17. US Department of Health and Human Services. For a healthy nation: returns on investment in public health. Washington, DC: US Government Printing Office; August 1994.
18. US Department of Health and Human Services, Centers for Disease Control, Dental Disease Prevention Activity. Water fluoridation: a manual for engineers and technicians. Atlanta; September 1986.
19. Institute of Medicine, Food, and Nutrition Board. Dietary reference intakes for calcium, phosphorus, magnesium, vitamin D and fluoride. Report of the Standing Committee on the Scientific Evaluation of Dietary Reference Intakes. Washington, DC: National Academy Press;1997.
20. Lambrou D, Larsen MJ, Fejerskov O, Tachos B. The effect of fluoride in saliva on remineralization of dental enamel in humans. Caries Res 1981;15(5):341-5.
21. Featherstone JD. The science and practice of caries prevention. J Am Dent Assoc 2000;131(7):887-99.
22. Dawes C. What is the critical pH and why does a tooth dissolve in acid? J Can Dent Assoc 2003;69(11):722-4.
23. Cate JM, Arends J. Remineralization of artificial enamel lesions *in vitro*. Caries Res 1977;11(5):277-86.
24. Yamazaki H, Litman A, Margolis HC. Effect of fluoride on artificial caries lesion progression and repair in human enamel: regulation of mineral deposition and dissolution under *in vivo*-like conditions. Arch Oral Biol 2007;52(2):110-20.
25. Proffit WR, Fields HW, Sarver DM. Contemporary orthodontics. 4th ed. St. Louis, Mo.: Mosby Elsevier; 2007.
26. Ewoldsen N, Demke RS. A review of orthodontic cements and adhesives. Am J Orthod Dentofacial Orthop 2001;120(1):45-8.
27. Anusavice KJ, Phillips RW. Phillips' science of dental materials. 10th ed. Philadelphia: W.B. Saunders; 1996.
28. Kocadereli I, Ciger S. Retention of orthodontic bands with three different cements. J Clin Pediatr Dent 1995;19(2):127-30.
29. Prosser HJ, Powis DR, Brant P, Wilson AD. Characterization of glass-ionomer cements. 7. The physical properties of current materials. J Dent 1984;12(3):231-40.
30. Saito S, Tosaki S, Hirota K. Characteristics of glass ionomer cements. In: Davidson CL, Mjor Ivar A, editors. Advances in glass ionomer cements. Chicago: Quintessence Publishing Co; 1999.
31. McComb D. Luting in orthodontic practice. In: Davidson CL, Mjor Ivar A, editors. Advances in glass ionomer cements. Chicago: Quintessence Publishing Co; 1999.

32. Fricker JP. A 12-month clinical study comparing four glass ionomer cements for the cementation of orthodontic molar bands. Aust Orthod J 1989;11(1):10-3.
33. Mizrahi E. Glass ionomer cements in orthodontics--an update. Am J Orthod Dentofacial Orthop 1988;93(6):505-7.
34. Nicholson JW. Chemistry of glass-ionomer cements: a review. Biomaterials 1998;19(6):485-94.
35. Ewoldsen N, Herwig L. Decay-inhibiting restorative materials: past and present. Compend Contin Educ Dent 1998;19(10):981-4, 86, 88 passim; quiz 92.
36. Diaz-Arnold AM, Vargas MA, Haselton DR. Current status of luting agents for fixed prosthodontics. J Prosthet Dent 1999;81(2):135-41.
37. Platt JA. Resin-based luting cements. Compend Contin Educ Dent 2000;21(9):740-2, 44.
38. Cacciafesta V, Bosch C, Melsen B. Clinical comparison between a resin-reinforced self-cured glass ionomer cement and a composite resin for direct bonding of orthodontic brackets. Part 2: Bonding on dry enamel and on enamel soaked with saliva. Clin Orthod Res 1999;2(4):186-93.
39. Small IC, Watson TF, Chadwick AV, Sidhu SK. Water sorption in resin-modified glass-ionomer cements: an *in vitro* comparison with other materials. Biomaterials 1998;19(6):545-50.
40. Barnett AH, Dreyer M, Lange P, Serdarevic-Pehar M. An open, randomized, parallel-group study to compare the efficacy and safety profile of inhaled human insulin (Exubera) with glibenclamide as adjunctive therapy in patients with type 2 diabetes poorly controlled on metformin. Diabetes Care 2006;29(8):1818-25.
41. Tate WH, You C, Powers JM. Bond strength of compomers to human enamel. Oper Dent 2000;25(4):283-91.
42. Abu-Bakr N, Han L, Okamoto A, Iwaku M. Changes in the mechanical properties and surface texture of compomer immersed in various media. J Prosthet Dent 2000;84(4):444-52.
43. Millett DT, McCluskey LA, McAuley F, et al. A comparative clinical trial of a compomer and a resin adhesive for orthodontic bonding. Angle Orthod 2000;70(3):233-40.
44. Preston AJ, Higham SM, Agalamanyi EA, Mair LH. Fluoride recharge of aesthetic dental materials. J Oral Rehabil 1999;26(12):936-40.
45. Millett DT, Cattanach D, McFadzean R, Pattison J, McColl J. Laboratory evaluation of a compomer and a resin-modified glass ionomer cement for orthodontic bonding. Angle Orthod 1999;69(1):58-63; discussion 64.
46. Markovic D, Petrovic B, Peric T. Fluoride content and recharge ability of five glassionomer dental materials. BMC Oral Health 2008;8(1):21.
47. Delbem AC, Pedrini D, Franca JG, Machado TM. Fluoride release/recharge from restorative materials--effect of fluoride gels and times. Operative Dentistry 2005;30(6):690-95.

48. Gandolfi MG, Chersoni S, Acquaviva GL, et al. Fluoride release and absorption at different pH from glass-ionomer cements. Dental materials : official publication of the Academy of Dental Materials 2006;22(5):441-49.
49. Kavaloglu Cildir S, Sandalli N. Compressive Strength, Surface Roughness, Fluoride Release and Recharge of Four New Fluoride-releasing Fissure Sealants. Dental Materials Journal 2007;26(3):335-41.