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03 June 2020

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6. Clearance ☑ Paper ☐ Article ☐ Book ☑ Presentation ☐ Other
7. Title Differences in Shear BOnd Strength Between Resin Composite and Glass Ionomers in the C
8. Intended Publication/Meeting General Dentistry
9. Required by 15 May 2020
10. Date of Submission 08 May 2020

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Differences in Shear Bond Strength Between Resin Composite and Glass Ionomers in the Open Sandwich Technique Using Different Generation of Adhesives

A Report on Shear Bond Strength Between Resin Composite and Glass ionomers
Presented to the Faculty of the Advanced Education in General Dentistry, Two-Year Program, Committee, United States Army Dental Activity, Fort Hood, Texas
In Partial Fulfillment of the Requirements of the Advanced Education in General Dentistry, Two-Year Program

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Fort Hood, Texas
May 2020

Abstract

Purpose: The aim of this study was to measure shear bond strength between composite and two glass ionomers using three different adhesive systems used between the glass ionomer and composite layers. The purpose was to determine what combinations will be most successful when applied to the open sandwich technique of restoring posterior teeth.

Methods: 108 samples were prepared for this study. Maxitemp was first placed into sample rings. Three wells were made into the Maxitemp of each ring using a round lab bur. Fifty-four wells were filled with Fuji II RMGI and cured and fifty-four wells were filled with Fuji IX GI and allowed to set. The samples were then polished with a Buehler Automet 3 Powerhead and Ecomet 6 variable speed polisher. After polishing, the two groups were separated into 3 additional groups per glass ionomer. One of three different adhesive systems was used per group. The three adhesive systems were Optibond Solo Plus, Clearfil SE Bond, and Scotchbond Universal. Filtek Supreme CR buttons were then applied to the surfaces of the glass ionomer/bonding agent using and Ultradent jig and cured. This created six different combinations with 18 samples per combination. The samples were then placed into a saline solution for 24 hours. After 24 hours the samples were tested with an MTS universal testing machine to test their shear bond strength.

Results: The results were 7.8 MPa for Fuji II, Optibond Solo Plus, Filtek Supreme group; 9.2 MPa for Fuji II, Clearfil SE Bond, Filtek Supreme; 10.8 MPa for Fuji II, Scotchbond Universal, Filtek Supreme; 5.2 MPa for Fuji IX, Optibond Solo Plus, Filtek Supreme; 6.5 MPa for Fuji IX, Clearfil SE Bond, Filtek Supreme; and 5.6 MPa for Fuji IX, Scotchbond Universal, Filtek Supreme.

Conclusion: There was a statistically significant difference in the mean shear bond strength of Fuji II compared to Fuji IX when bonded to composite resin. There was a statistically significant difference in the shear bond strength of Optibond Solo plus when compared to Scotchbond Universal and Clearfil SE bond. There was not a statistically significant difference in the shear bond strength between Scotchbond Universal and Clearfil SE bond. The combination that had the greatest shear bond strength was the Fuji II/Scotchbond Universal group.

Acknowledgements

The Author would like to thank the following:

- Dr. Wen Lien of the U.S. Air Force Dental Evaluation and Consultation Services (DECS) for assistance with research protocol, data collection, and data interpretation.

- Dr. John Kreider of the U.S. Army Fort Hood Advanced Education in General Dentistry residency for assistance with revisions of thesis and thesis defense presentation.

- Dr. John King of the U.S. Army Fort Hood Advanced Education in General Dentistry residency for assistance with research protocol

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Introduction:

Restorations that are deep and have margins that are placed onto cementum or dentin are more likely to decay [(1)]. Secondary caries is a major indication for replacement of fillings. Reasons for increased caries on dentin and cementum margins are as follows: difficulty gaining access to deep margins, poor dentinal bonding, poor isolation, and difficulty restoring these restorations [(2)]. The nature of composite resin restorations makes them susceptible to these problems. Resins are very good at bonding to enamel, but in a deep cervical margin where there is no enamel, they have poor bond strength and a high rate of failure [(3)]. Cementum lacks patent tubule orifices which may also alter the bonding capacity of composite resin. Poor bond strength in association with polymerization shrinkage increases the rate of secondary decay. Amalgam is an appropriate choice, but esthetic concerns make it undesirable for some patients [(4)]. These reasons have led to the development of alternate restorations [(5)].

One of these alternatives is the open sandwich technique. The name open sandwich is derived from placing a layer of glass ionomer between the tooth and a layer of composite resin. It is considered open because the glass ionomer creates the margin in the proximal box of the cavity preparation and communicates with the oral environment. In a closed sandwich restoration, the composite creates the full margin of the restoration [(6)]. This technique is not new, however, it was originally used by Mclean and Wilson in 1977. They left glass-ionomer cement exposed to the cervical margin to allow fluoride release and protect the surrounding tooth structure [(7)]. The first open sandwich restorations used conventional glass ionomer cements, and they were recommended for high caries risk patients. They had high moisture sensitivity which caused progressive loss of glass ionomer cement. Resin modified glass ionomer cements (RMGIC) and highly viscous conventional glass ionomer cements were later introduced and they

showed improved handling characteristics. RMGIC and highly viscous conventional glass ionomer cements improve the outer marginal seal of the restoration in the open sandwich restoration [8].

Glass ionomers also release fluoride, which can influence the caries process [9]. Fluoride is present in other restorative materials such as Giomers and Compomers, but the fluoride release of these materials is significantly less than the fluoride release from Glass Ionomers [10]. One study tested the hardness of a glass ionomer restoration bonded to dentin after demineralizing the margin and found that the dentin around a glass ionomer was harder than the dentin around composite resin [11]. Another study by Ten Cate and Van Duinen showed that incipient caries had hyper mineralization after placement of an open-sandwich restoration whereas the contralateral side with amalgam and resin composite fillings showed demineralization. The amount of fluoride that is released from glass ionomers is initially high, but decreases significantly after a couple of weeks. The long-term level of release for restorations depends on the ability of the cement to absorb fluoride form toothpaste and the patient's diet [12].

Glass ionomers chemically bond to dentin via an acid-base reaction [13]. This chemical bond helps reduce sensitivity and microleakage [14]. Composite resins produce polymerization contraction, which may lead to gap formation. Gap formation is susceptible to hydrolytic degradation and microleakage. Microleakage is a common reason for the failure and replacement of composite restorations [15]. Modern glass ionomers are made up of about 25% water, and they are less susceptible to moisture contamination then composite resins [16]. Unfortunately, glass ionomers do not have the strength to hold up to the occlusal forces of the mouth. They have less tensile strength, poor abrasion resistance and are less color stable as compared to composites [17]. Because of this, composite resin is placed on the glass ionomer to

absorb occlusal forces in the open sandwich technique. This layering technique has the advantage of replacing tooth structures with materials that have similar properties to what they are replacing [18]. The glass-ionomer/composite sandwich configuration is an example of the biomimetic principle. It emulates the structure and properties of natural teeth. GI serves as a dentin replacement and resin acts as the enamel replacement [19]. Glass ionomer's coefficient of thermal expansion is close to dentin, and composite is more like enamel [20].

Glass ionomers are a class of materials known as acid base cements and they have three essential ingredients. Polymeric water-soluble acid, basic glass, and water. When mixed, the polymeric acids react with the basic powdered glasses. Setting occurs in concentrated solutions of water and set glass ionomer contains a large amount of unreacted glass, which acts as a filler to reinforce the cement. Glass ionomers come in two formulations as follow: the first, a mixed solution of aqueous polymeric acid and glass powder to form a viscous paste and the second, a polymeric acid with glass in the powder which is added to water [21].

The polymers used in glass-ionomers are polyalkenoic acids (usually polyacrylic acid). The molecular structure of the polymer changes the properties of the glass ionomer. A higher molecular weight increases the strength of the cement, but if it is too heavy, it becomes highly viscous and difficult to mix. The glass component needs to be basic so it can react with the acidic polymer. There is a large variation in the composition of the base used in glass ionomers but, usually, alumino-silicate glasses with fluoride, sodium, calcium, and phosphate are used [22]. Water is an essential component of glass ionomers. It is the solvent for polyacrylic acid, allows the polymer to act as an acid by promoting proton release, the medium of the setting reaction, and a component of set glass ionomer cement [23].

Glass ionomers generally set within 2-3 min from being mixed. First, there is a reaction from the polyacid at basic sites of the surface of the glass particles, which is commonly from Na+, Ca2+, or Al3+ components of the glass. These components form ionic crosslinks to the polyacid molecules [24]. This creates an immediate hardening process. When the reaction occurs, all the water becomes incorporated into the cement. After the initial hardening, there are further reactions known as maturation. Maturation leads to increased strength and translucency. Chelating agents are added to glass ionomers to modify the rate at which glass ionomers set. The two most common agents are tartaric acid and citric acid, which prevent the precipitation of aluminum salts by blockading the premature formation of ionic crosslinks. This delays the setting reaction time so that the cement is easier to mix. After this initial delay, the cement will then set very quickly [25].

An advantage of glass ionomer restorations is their adhesion to tooth structure. Application of the glass ionomer wets the tooth surface through the hydrophilic nature of both the cement and tooth surface [26]. Hydrogen bonds form between the carboxyl groups of the cement and the water on the tooth surface. The hydrogen bonds are slowly replaced by ionic bonds between cations of the tooth and anionic carboxyl groups of the cement. The tooth surface can be prepared by conditioning with 20% aqueous polyacrylic to increase the bond strength. This removes the smear layer, opens dentin tubules, demineralizes the tooth surface, and increases micro mechanical bonding [27]. There are two types of bonding that can occur from glass ionomers and tooth structure. Micromechanical interlocking of the glass ionomer and the tooth surface and chemical bonding between polyacrylic acid and calcium cations of the tooth surface. Failure of glass ionomer cement is usually cohesive and not adhesive.

Glass ionomers were originally introduced in the early 1970s. Their progression has been

dramatic, but they all have similar chemical properties [28]. The invention of glass ionomer cements came from studies of silicate cements. Phosphoric acid of dental silicate cements was replaced by acrylic acid. The first generation of glass ionomer cement produced by Wilson and Kent in 1972 was called ASPA. This cement set slowly, was susceptible to moisture, and had poor esthetic properties [29]. The resolution was to add tartaric acid, which improves manipulation and extends working time. It allowed the use of glass with a lower fluoride content, which improved esthetics. The new glass ionomer was called ASPA II. The liquid portion of ASPA II was a 50% solution of polyacrylic acid that would gel over time. Methyl alcohol was added to the formulation later to inhibit gelling and called ASPA III. Since ASPA III stained the mouth, a copolymer of acrylic and itaconic acid was created that stabilized in a 50% aqueous solution and called ASPA IV. This became the first commercial marketable glass ionomer cement [30].

The second generation of glass ionomer cements were water hardening. When poly acrylic acid is in solution, it has a high molecular weight and high viscosity which makes it difficult to manipulate. One way around this is to combine the glass ionomer powder with a solid form of polyacrylic acid. The liquid that is added is either plain water or aqueous tartaric acid. This improves shelf life since there is no longer a possibility of gelation. It also allows the development of low viscosity glass ionomers that have higher strength. Reinforced glass ionomers were created to increase the tensile strength. This included adding metal powder, amalgam, or sintering metal and glass powders together. These techniques did increase the tensile strength, but not significantly enough to be used in high stress areas. They also had the downside of being unaesthetic [31].

Glass ionomer cements still had the problem of moisture susceptibility and lack of

command cure. In the late 1980s and early 1990s, light cured glass ionomers called Resin-Modified were developed [32]. The acid/base curing reaction is supplemented by light curing process [33]. A small amount of resin, usually hydroxyethyl methacrylate or Bis-GMA is added in the liquid along with a photo initiator such as camphorquinone. The glass ionomers maintain their ability to chemical cure, but also have the ability to light cure [34]. RMGIs have greater working time, command set, good adaptation, superior strength, and esthetics similar to composite resin. They have the drawbacks of setting shrinkage and limited depth of cure [35]. One of the glass ionomers used in this study, Fuji II, is an example of a RMGI cement.

Highly viscous conventional glass ionomer cement was developed to make placement of glass ionomer similar to amalgam. It was designed as an alternative to amalgam for posterior preventative restorations. The higher viscosity is the result of addition of polyacrylic acid to the basic glass powder and finer grain size distribution. They set rapidly, have reduced moisture sensitivity, and low solubility [36]. One example of this traditional glass ionomer is Fuji IX, which is used in this study.

Dental adhesive systems were developed in the 1950s. Originally, these systems had very poor clinical results and low bond strengths [37]. It wasn't until the 1980s and 1990s that modern adhesive systems were developed. These systems consist of three main components: etchant, primer, and adhesive bonding resin. The etchant is typically 35-37% phosphoric acid. It prepares enamel and dentin for the primer by making micro porosities for micro mechanical bonding. The primer is composed of hydrophilic monomers carried in a water-soluble solvent for good flow and penetration into hydrophilic dentin [38]. Dentin bonding resins are a thin layer of resin that is between conditioned dentin and the composite resin restoration. It acts as the link between hydrophilic resin primer and hydrophobic resin composite. The first adhesive systems

that had these three components are called fourth generation dentin bonding agents. Each of the components is packaged separately in these adhesive systems. Etch is first placed for 15-20 seconds and then rinsed to completely remove the smear layer, but the surface of the tooth is left moist to avoid collagen collapse. A hydrophilic primer, typically 2-Hydroxy ethyl meth-acrylate (HEMA), dissolved in a solvent is then able to infiltrate the exposed collagen network [(39)]. The solvent is removed by air drying and a solvent free adhesive resin is applied. This forms a hybrid layer which is a resin infiltrated surface layer on dentin and enamel. The hybrid layer gives a higher bond strength and a dentin seal. The three-step system is very effective and is considered the "benchmark" in dentin bonding. The disadvantage is that it requires multiple application steps. Because of this, simplified adhesive systems were developed [(40)].

The next system to be developed was a simplified two step version of the three-step etch and rinse system. This adhesive system combines the primer and bond into one solution. The downside to these systems is that they are very technique sensitive and can have a reduced ability to infiltrate dentin [(41)]. They create a poor hybrid layer when compared to the three-step system. If dentin is over dried, the collagen fibers collapse which leads to low monomer diffusion of the combined primer and bond. The solvent in the primer is also more difficult to evaporate causing the solvent to be trapped within the adhesive layer. If the dentin is left too wet, there can be phase separation between the hydrophobic and hydrophilic component of the adhesive. If done correctly, the two-step system has the same shear bond strength as the three-step system [(42)]. One example of this is Optibond Solo Plus, which is used in this study.

Self-etching systems were the next adhesive systems to be developed. They consist of having a self-etching primer as one component and having a separate hydrophobic bond resin component [(43)]. The self-etching primers are an aqueous solution of acidic functional monomers

that simultaneously etch dentin and infiltrate dentin and enamel. The pH of the self-etching primer is higher than that of phosphoric acid etchants. Because of the high pH, they do not completely remove but, instead, modify the smear layer [44]. Since the smear layer is not removed, it is incorporated into the hybrid layer [45]. One advantage to this is that the hydration state of the collagen is not as important. Self-etching systems also claim to have less post-operative sensitivity since the smear layer is not removed, and there are fewer dentinal tubules exposed. This leads to less dentinal fluid flow than etch and rinse systems. The disadvantage of these system is that since the self-etching primer has a higher pH, it does not etch enamel as well. This leads to a bond to enamel that can be 25% weaker then etch and rinse systems [46]. The example of this system used in this study is Clearfil SE Bond.

One step self-etching systems were developed next. They combined a self-etching primer with the bond component [47], but were not as clinically successful as prior adhesive systems. Their chemical makeup forced them to be very hydrophilic which made the adhesive layer prone to attract water, so the bond strength degraded over time. Universal adhesive systems were developed in response to this. The chemical makeup of the monomers was changed so that their bond did not degrade over time. Also, they were designed so that they still bond to tooth structure that is etched [48]. This has the advantage that enamel can be selectively etched to achieve a stronger enamel bond [49]. The example of this adhesive system used in this study is Scotchbond Universal.

The bond between glass ionomer and composite resin is similar to the bond between composite resin and tooth structure. Adhesive systems significantly improve the bond strength of composite resin to glass ionomers [50]. This bond is a micromechanical bond between the

resin and adhesive system to conventional glass ionomers [51]. In resin modified glass ionomers, there is also a chemical bond between the resin component of the RMGI.

This study tests the difference between different adhesive generations to both a highly viscous conventional GI and a RMGI [52]. There have not been very many studies that have been done to test the bond strengths of glass ionomers and composite resins. This study is focused on the materials that are readily available to dentists in the U.S. Army.

Purpose:

The purpose of this study was to test the differences in shear bond strength between the interface of glass ionomers with composite resin in the open sandwich technique. It focused on materials that are easily available for Army dentists. These being the two glass ionomers (Fuji II and Fuji IX) and 3 adhesive systems (Scotchbond Universal, Clearfil SE Bond, and Optibond Solo Plus). These glass ionomers and adhesive systems were bonded to Filtek Supreme Ultra CR. The results were analyzed to see if there is a statistical difference in the bond using different glass ionomers and adhesive systems.

Hypothesis:

Research question 1: Is there a difference in the shear bond strength between Fuji II and Fuji IX when bonded to composite resin?

Research question 2: Is there a difference in the shear bond strength between glass ionomer and composite resin when using three different adhesive systems? (Optibond Solo Plus, Clearfil SE Bond and Scotchbond Universal Adhesive)

Research question 3: Is there a combination of the studied glass ionomers and adhesive systems that gives a stronger shear bond strength?

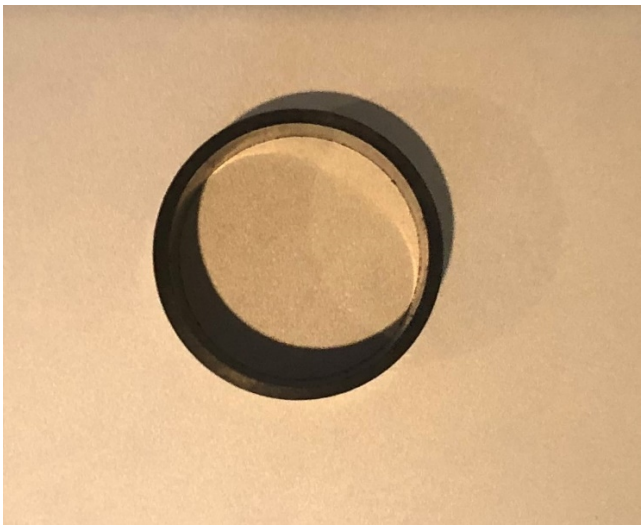
Null hypothesis 1: There will be no difference in shear bond strength Fuji II and Fuji IX when bonded to composite resin.

Null hypothesis 2: There will be no difference in shear bond between glass ionomer and composite resin when using three different adhesive systems. (Optibond Solo Plus, Clearfil SE and Scotchbond Universal Adhesive)

Null hypothesis 3: There will be no difference in the combination of the studied glass ionomers and adhesive systems that gives a stronger shear bond strength

Methods and Materials:

MaxiTemp was used as a base material and placed into 36 1.25-inch sample rings (picture 1). The rings were for a Buehler Automet 3 Powerhead and Ecomet 6 Variable Speed Polisher (SN 586-A3P-00411) (picture 2). Before filling the rings, undercuts were made into the rings with a lab bur to prevent the MaxiTemp from sliding in the rings. The rings were then placed against a smooth surface, filled about three quarters of the way full of MaxiTemp, and allowed to chemically cure.



Picture 1: Sample ring

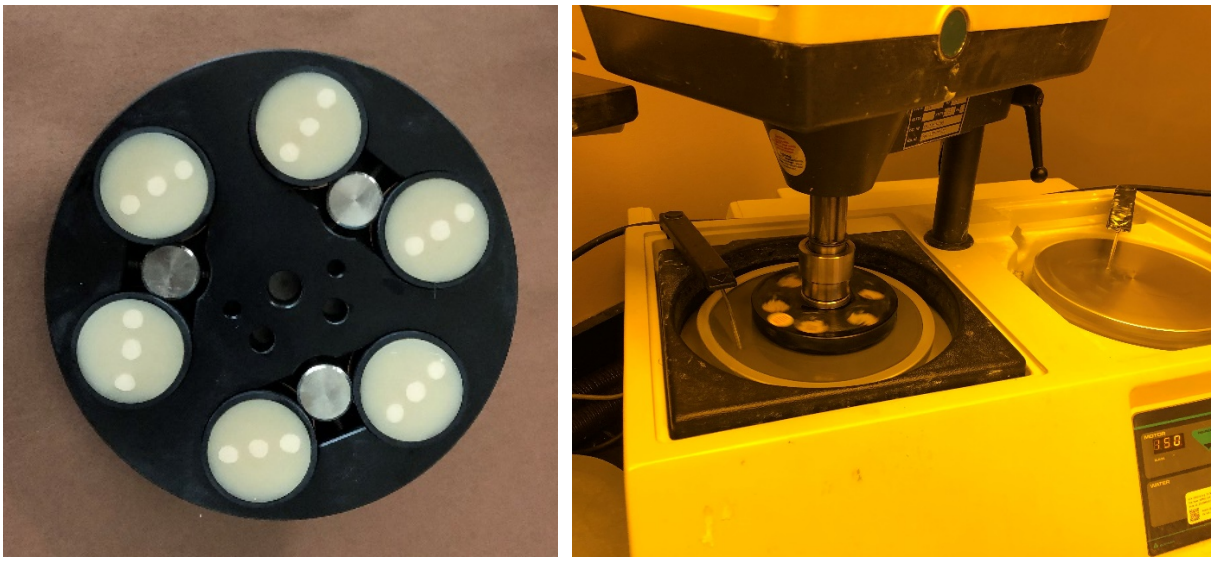
Picture 2: Buehler Automet 3 powerhead and Ecomet 6 Variable Speed Polisher

Three wells were made into each ring using a lab bur. The wells were about 4mm in circumference and at least 4mm deep with undercut (picture 3a). GC cavity conditioner (20% polyacrylic acid and 3% aluminum chloride) was placed into the wells for 10 seconds and rinsed

(picture 3b). Fifty-four of the wells were filled with Fuji II resin modified glass ionomer from capsules that were mixed for 10 seconds. They were then light cured for 20 seconds. The other Fifty-four wells were filled with Fuji IX glass ionomer from capsules that were mixed for 10 seconds and allowed to chemically set. These first steps were completed at Billy Johnson Dental Clinic. The samples were then transferred to Fort Sam Houston, San Antonio, TX at the USAF Dental Evaluations and Consultation Service (DECS). The remainder of the experiment was completed there.

Picture 3: (a) Maxitemp wells, (b) wells with GC cavity conditioner

The 36 rings were initially smoothed with a lab grinder. Then a Buehler Automet 3 Powerhead and Ecomet 6 Variable Speed Polisher was used to polish the samples (picture 4). The samples were polished for 15 min each with 320, 400, and 600 grit sandpapers.



Picture 4: (a) Buehler Automet 3 powerhead specimen holder with specimens, (b) Samples being polished

Picture 5: Polished sample

Each glass ionomer group was then separated into three additional groups and a different adhesive system was used in each group. This made a total of six groups of 18 specimens each (figure 1). The three adhesive systems used per glass ionomer were Optibond Solo Plus, Clearfil SE Bond, and Scotchbond Universal. For the Optibond Solo specimens, the samples were etched with 37.5% phosphoric acid for 15 seconds and rinsed. Optibond Solo was then applied to the GI with an applicator tip, using a light brushing motion. They were then air thinned for 5 seconds and light cured for 20 seconds. For the Clearfil SE specimens, primer was applied to the GI with an applicator brush and left in place for 20 seconds. Mild air was used for 5 seconds to dry the primer. Next, bond was applied to the GI with an applicator brush and then light cured for 10 seconds. For Scotchbond Universal, the adhesive was applied to the GI and rubbed into

the GI with and applicator brush for 20 seconds. A gentle stream of air was then applied to the Scotchbond Universal for 5 seconds. Finally, it was light cured for 10 seconds.

Filtek Supreme CR buttons were then applied to the surfaces of the glass ionomer/bonding agent. This was done according to ISO 29022. An Ultradent jig was used with a standardized button mold (picture 6) and bonding clamp to bond the composite to the glass ionomer. The buttons were about 2.33mm in diameter. The six groups of 18 specimens that were made were: Fuji II, Optibond Solo, Filtek Supreme; Fuji II Clearifil SE Bond, Filtek Supreme; Fuji II, Scotchbond Universal, Filtek Supreme; Fuji IX, Optibond Solo, Filtek Supreme; Fuji IX, Clearifil SE Bond, Filtek Supreme; and Fuji IX, Scotchbond Universal, Filtek Supreme. (Figures 1a and 1b)

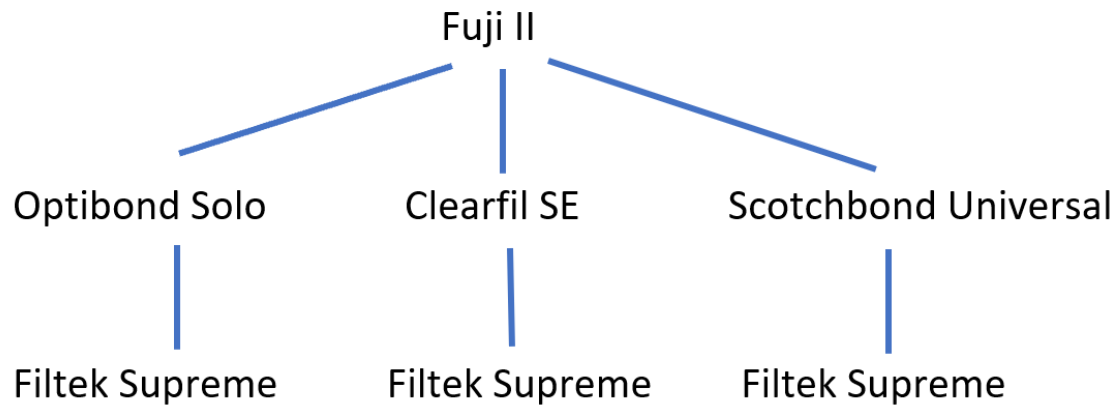


Figure 1a: Outline of Fuji II sample combinations

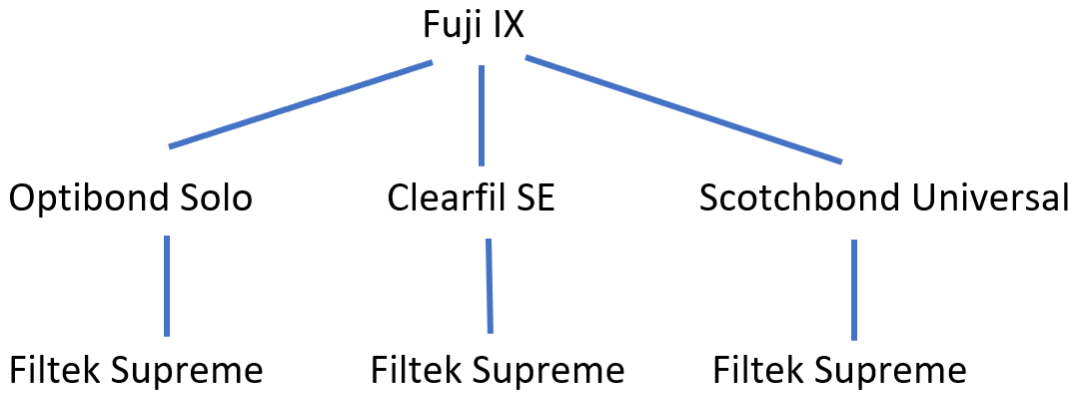
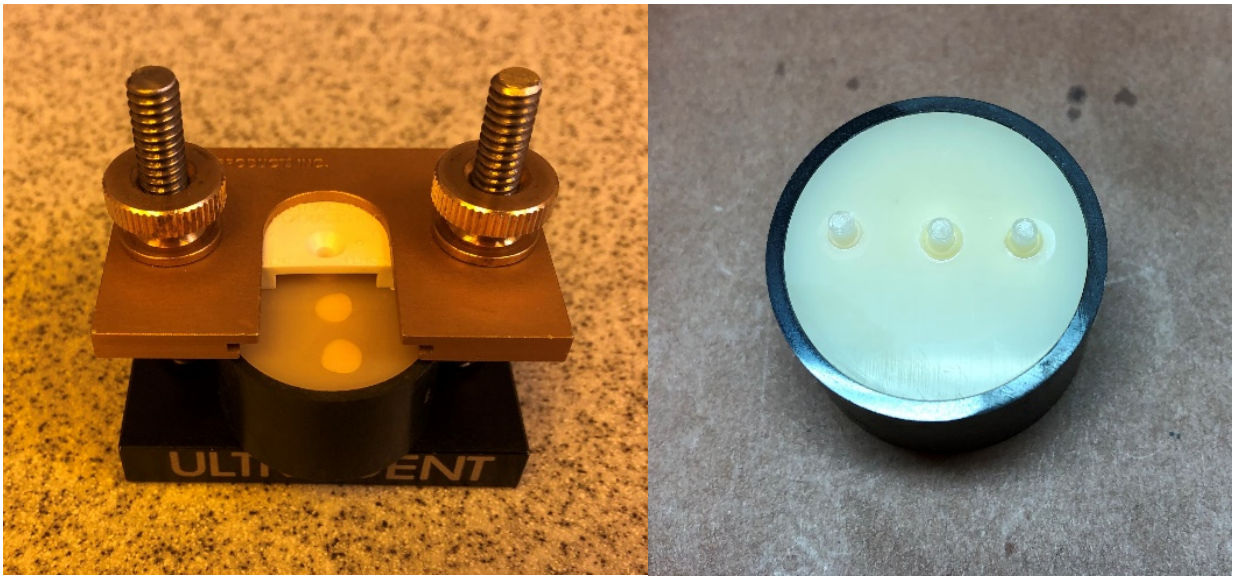


Figure 1b: Outline of Fuji IX sample combinations

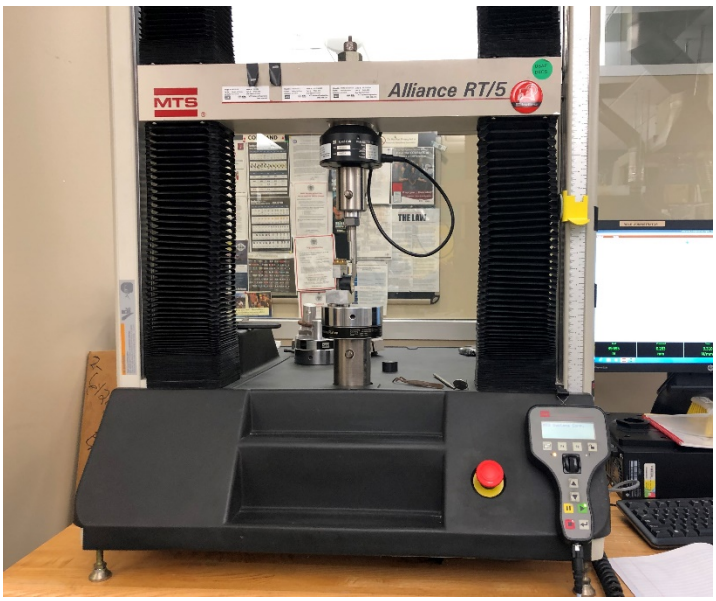


Picture 6: (a) Ultradent jig placed on samples (b) After samples were placed

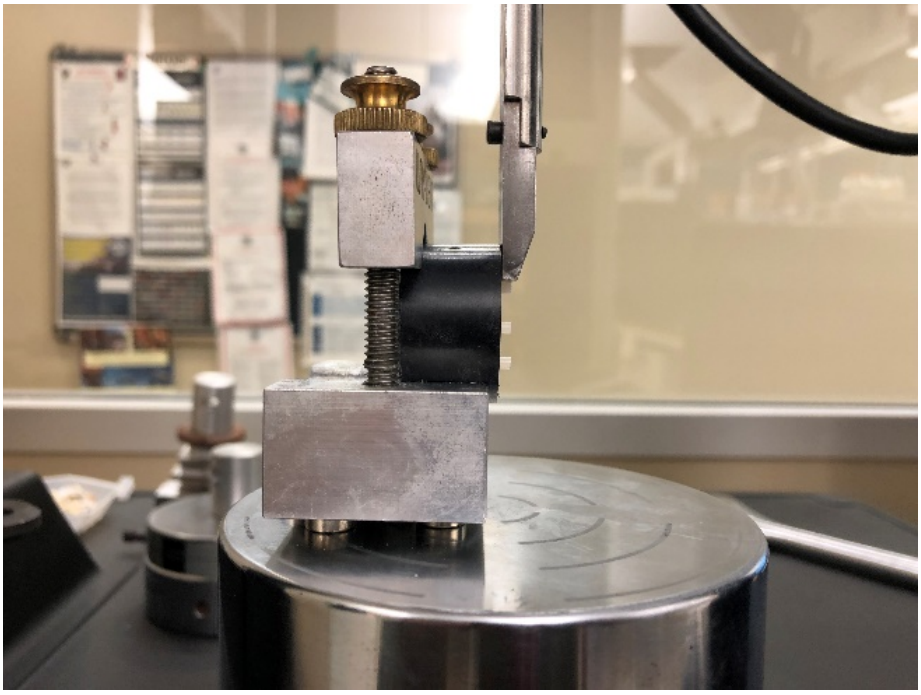
After making the samples, they were placed into water for 24 hours (picture 7). After 24 hours they were taken out of the water and allowed to dry. Next the samples were tested with an MTS universal testing machine (picture 8). Each ring was placed into an Ultradent test base clamp and then placed into the MTS machine. They were placed so that the three buttons were positioned vertically (picture 9). A force was applied to the button by the MTS testing machine until the button broke. This force was then recorded. Even though the buttons were made from

the Ultradent jig and button mold, they had a slight variance in diameter. Because of this, the diameters of the buttons were measured after they were broken. This was done so an accurate bond strength could be calculated. After testing, the samples were looked at under a light microscope to see if the bond failures were adhesive or cohesive (picture 10).

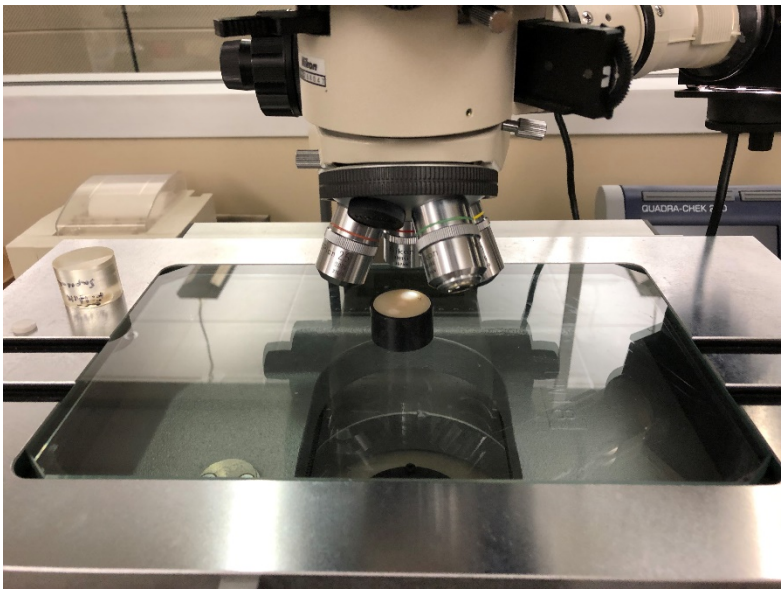
Picture 7: Samples placed in water for 24 hours



Picture 8: MTS universal testing machine



Picture 9: Samples were placed vertically and tested



Picture 10: Samples looked at under a microscope.

Results:

A total of 108 samples were made for this study. This included 18 samples from six different groups. The six groups of 18 specimens that were made were: Fuji II, Scotchbond Universal, Filtek Supreme (IISU); Fuji II Clearifil SE Bond, Filtek Supreme (IICSE); Fuji II, Optibond Solo, Filtek Supreme (IIOS); Fuji IX, Scotchbond Universal, Filtek Supreme (IXSU); Fuji IX, Clearifil SE Bond, Filtek Supreme (IXCSE); and Fuji IX, Optibond Solo, Filtek Supreme (IXOS). Two samples de-bonded before the shear bond test was started and they were not included in the study. They were one sample for the IXSU and IXOS groups. These two groups had 17 samples included in the study. A two-way ANOVA test with Tukey's post hoc was completed for statistical analysis.

When calculating the results of the mean shear bond strength for each adhesive system, not taking into consideration which glass ionomer was used, the results were as follows: 8.32 MPa for Scotchbond Universal with a standard deviation of 2.91. For Clearfil SE Bond it was 7.85 MPa with a SD of 2.62. For OptiBond Solo Plus the mean bond strength was 6.54 with a SD of 1.95. (Figure 2) When taking into account the adhesive system without considering the type of glass ionomer, Scotchbond Universal and Clearfil SE Bond were not statistically significantly different from each other. OptiBond solo Plus had a statistically significantly weaker bond strength then Scotchbond Universal and Clearfil SE Bond.

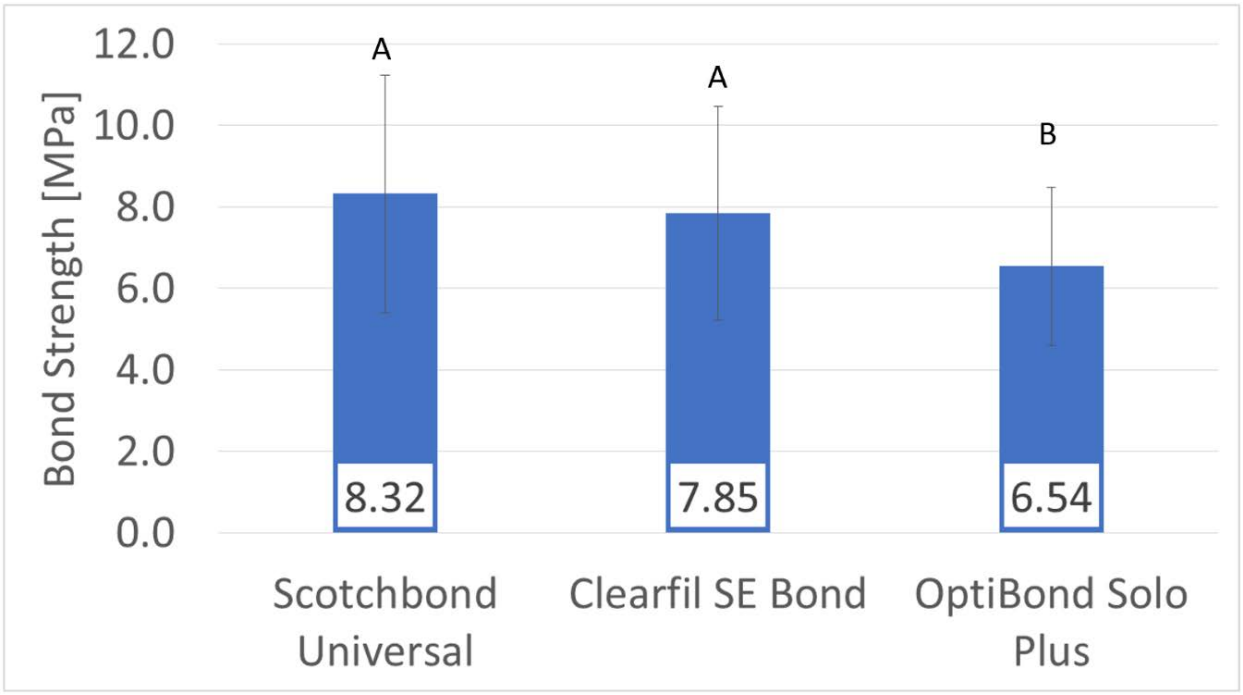


Figure 2: Mean shear bond strength of tested adhesive systems. The letters show which combinations were and were not statistically significant from each other. If a combination has the same letter, there was not a statistically significant difference.

When calculating the mean shear bond strength of each glass ionomer without taking into consideration which adhesive system was used the results were: 9.31 MPa with a SD of 2.34 for Fuji II RMGI and 5.78 MPa with a SD of 1.36 for Fuji IX GI. (Figure 3) When taking into account the type of glass ionomer without considering the adhesive system, Fuji II RMGI had a statistically significant greater bond strength then Fuji IX GI.

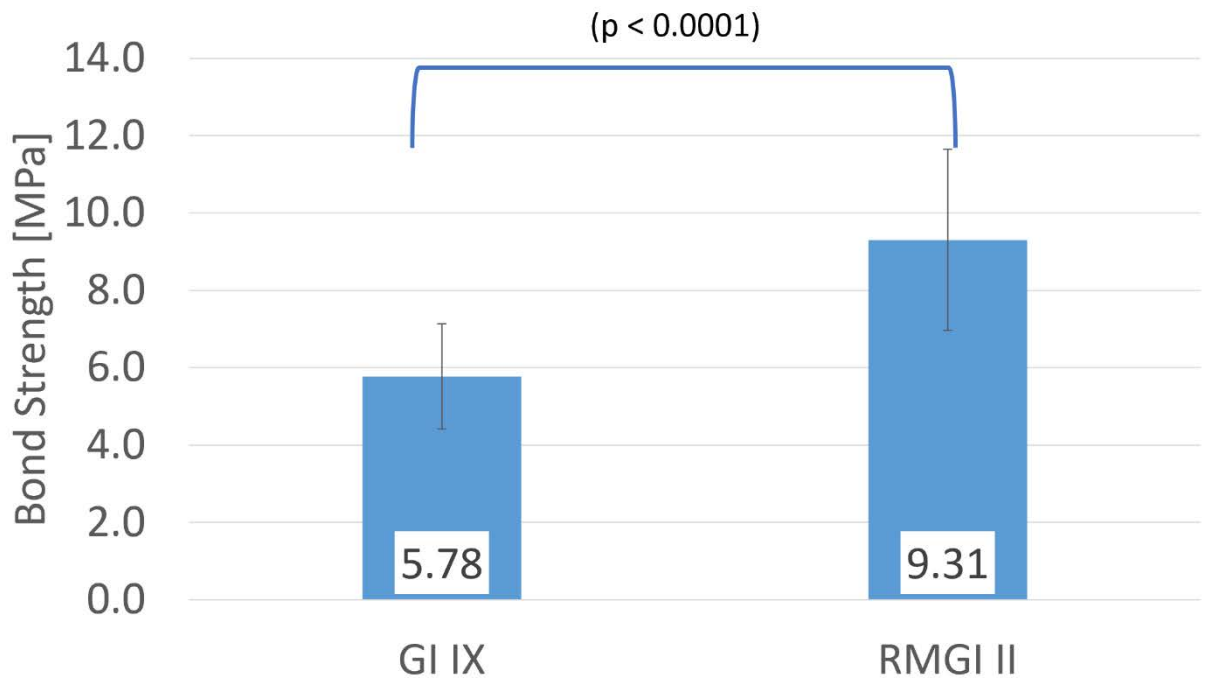


Figure 3: Mean shear bond strength of Fuji II and Fuji IX

When taking into consideration both the type of glass ionomer and adhesive system used the mean shear strength were as follows. For IISU it was 10.83 MPa with a SD of 1.40, for IICSE, 9.24 MPa with a SD of 2.81; for IIOS, 7.85 MPa with a SD of 1.60; for IXSU, 5.67 MPa with a SD of 1.2; for IXCSE, 6.45 MPa with a SD of 1.45 and for IXOS 5.17 MPa with a SD of 1.19. IISU had the highest shear bond strength. Some of the glass ionomer/adhesive systems were statistically significant from each other, but not all. Figure 4 shows which groups were and were not statistically significant from each other.

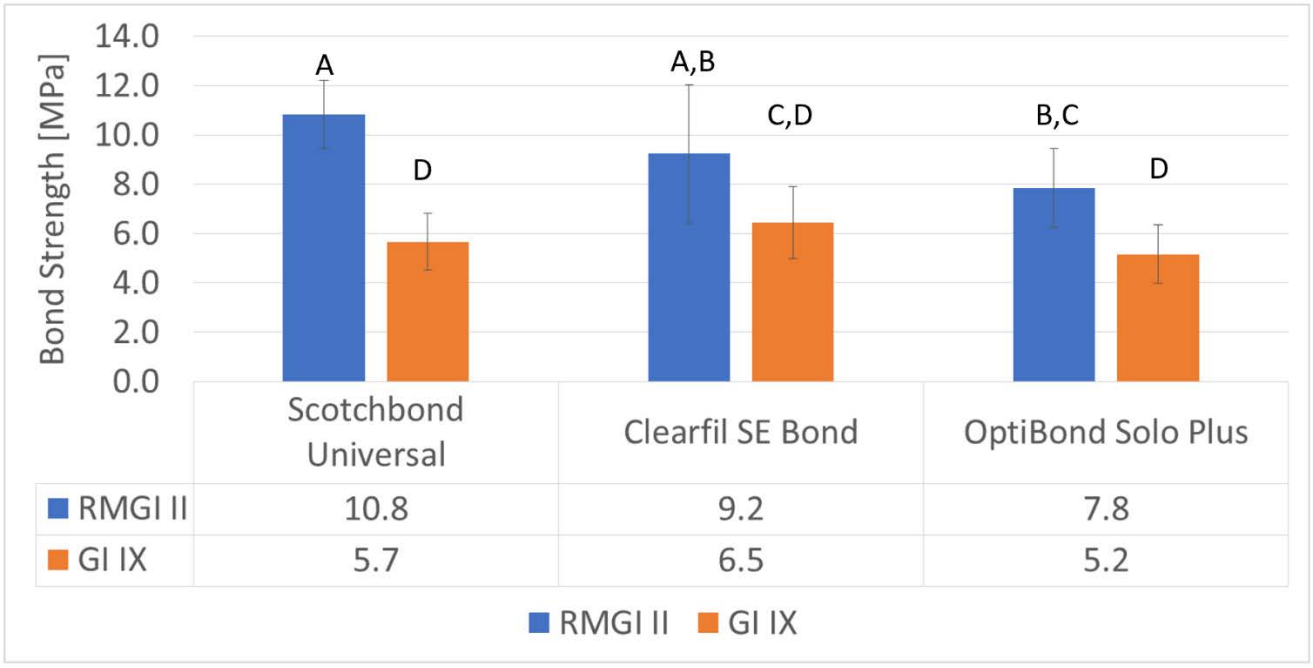


Figure 4: Mean shear bond strength of glass ionomers and adhesive systems. The letters show which combinations were and were not statistically significant from each other. If a combination has the same letter, there was not a statistically significant difference.

The results of the location of the bond failures for each adhesive system are shown in figure 5. For Clearfil SE bond 33.3% were adhesive failures. 8.3% were cohesive within the composite and 58.8% cohesive within the glass ionomer. For Optibond Solo 19.4% were adhesive failures. 8.3% were cohesive within the composite and 69.4% were cohesive with the glass ionomer. For Scotchbond Universal 8.3% were adhesive failures. There were no cohesive failures within the composite and the cohesive failure rate within the glass ionomer was 91.7%.

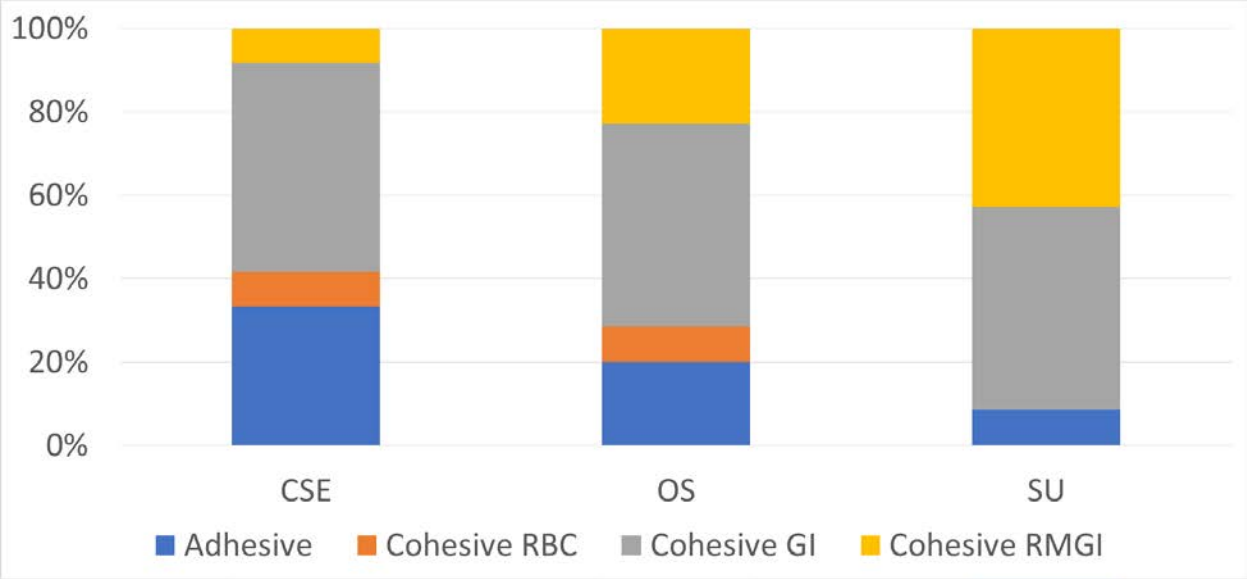


Figure 5: Failure location of adhesive systems

The results of the location of the bond failures for the two-glass ionomers used are shown in figure 5. For Fuji IX 100% of the failure were cohesive within the glass ionomer. For Fuji II 40.7% were adhesive failures. 11.1% were cohesive within the composite and 48.1% were cohesive within the glass ionomer

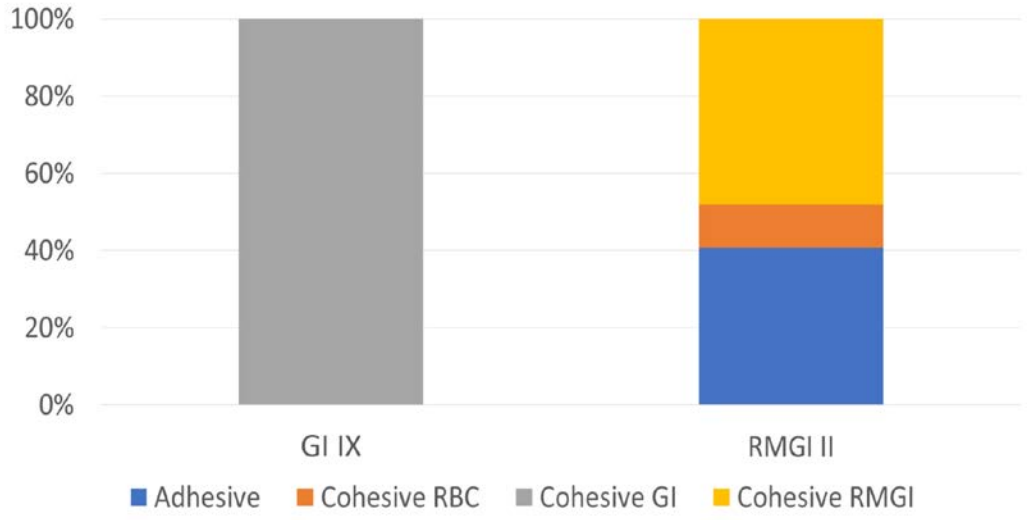


Figure 6: Failure location of glass ionomers

Discussion:

Deep interproximal lesions are a challenge to restore. In these lesions, the interproximal box is placed on cementum and dentin. Composite resins do not bond well to cementum or dentin. This leads to an increased rate of secondary decay. The open sandwich technique was developed to try to decrease the rate of secondary caries. It consists of placing a glass ionomer layer in the proximal box over cementum and dentin, and then finishing the restoration with composite resin. Knowing what type of glass ionomer and adhesive system has the strongest bond strength is beneficial in choosing the appropriate materials.

When the type of glass ionomer was not taken into consideration there was no statistical significance in bond strengths between Scotchbond universal and Clearfil SE Bond. Both Scotchbond Univeral and Clearfil SE Bond did have statistically significant different bond strengths to Optibond Solo Plus, with Optibond Solo Plus having a weaker bond. This suggests that self-etch adhesives bond more strongly to glass ionomers than etch and rinse adhesives. Etch and rinse systems could potentially increase bond strength because etching could increase the porosity of glass ionomers during bonding. However, according to Pamir et al., there is no consensus to the effectiveness of this [53]. One possible reason for the increased effectiveness of Clearfil SE and Scotchbond Universal is that these adhesives contain the functional monomer 10-MDP. 10-MDP can form an ionic bond with calcium, which is in glass ionomers.

When the type of adhesive was not taken into consideration there was a statistically significant difference between the shear bond strengths between Fuji II and Fuji IX. Microscopic analysis of the samples showed that all of the Fuji IX samples had cohesive failure within the Glass Ionomer. With Fuji II the failures were a combination of adhesive (40.7%), cohesive within the glass ionomer (48.1%), and cohesive within Filtek Supreme CR (11.1%). These

results suggest that the limiting factor in the Fuji IX/CR bond was the strength of the Fuji IX itself. With Fuji II, the bond failure was spread between the three different types of failures, which suggests that the strength of Fuji II was not the limiting factor in the bond strength between the bond between Fuji II and composite resin. Fuji II is a RMGI and Fuji IX is a conventional glass ionomer. One possible reason for this is that, according to Li et al., the resin within Fuji II increases the cohesive bond strength of resin modified glass ionomer [(54)]. There could also be an increased bond strength to RMGI since the adhesive system can react with the residual monomer in RMGI [(55)].

When both the adhesive and type of glass ionomer were taken into account, the IISU group had the strongest shear bond strength. It was not statistically significantly compared to IISE. IISU was statistically significantly compared to IIOS but there was no statistical difference between IISE and IIOS. The differences between IXSU, IXSE, and IXOS were not statistically significant. IXSE had the largest shear bond strength of the Fuji IX groups. Its shear bond strength was not statistically significant from that of IIOS. IISU had the highest shear bond strength. Most of its failures were in the glass ionomer (83.3%). IISE and IIOS groups did not have a consistent mode of failure. This suggests that the bond strength of the Scotchbond Universal was stronger than the cohesive strength of Fuji II glass ionomer, but for IISE and IIOS it was not.

Future studies:

1. Test the shear bond strength between the glass ionomer and tooth structure. The open sandwich technique places glass ionomer in the proximal boxes of class II cavity preparations. Another area of interest would be testing the glass ionomer bond to dentin, cementum, and enamel.

2. The same samples could have been used but other physical properties could have been tested. Flexural bond strengths could have been another way to test the bond between glass ionomers and CR. Other physical properties like compressive strength, tensile strength, and fracture toughness could be studied.

3. Scotchbond Universal, Clearfil SE Bond, and Optibond Solo Plus were used in this study because they are common adhesive systems that are available for providers in the Army. There are a lot of other popular adhesive systems that also could be studied and then utilized by the US Army

4. Fuji II and Fuji IX were used in this study because they are the most readily available glass ionomers in rhe Army. Other common glass ionomers could be tested and then utilized by the US Army.

5. Bench top studies have limitations. Design in vivo study to test the shear bond strengths of the samples. If it is not possible in human clinical trials consider animal trials.

Conclusion:

The results of the study led to the following conclusions:

1. There was a statistically significant difference in the mean shear bond strength of Fuji II compared to Fuji IX when bonded to composite resin. This disproves the first null hypothesis.

2. These was a statistically significant difference in the shear bond strength of Optibond Solo plus when compared to Scotchbond Universal and Clearfil SE bond. There was not a statistically significant difference in the shear bond strength between Scothbond Universal and Clearfil SE bond. This disproves the second null hypothesis.

3. When taking into consideration both the type of glass ionomer and the adhesive

system, some of the combinations had a statistically significant difference and some did not (Figure 4). This disproves the third null hypothesis.

Conflict of Interest

The authors certify that they have no proprietary, financial, or other personal interest of any kind in any product, service, and/or company that is presented in this paper.

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