Shear bond strength of DentStat^{TM} for bracket bonding to gold, ceramic, and enamel.

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San Antonio, TX

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DEDICATION

This thesis is dedicated to my family. The time and effort put into this education has come at the expense of time spent with you. Thank you Paige, my eternal love, for your unequaled support, being there for me and the kids over these last several years. There were many times over these years when you were a single parent raising five children and taking care of a household. Thank you Lydia, Taylor, Brienz, Aidylein, and Ruth for reminding me about what the important things are in life. Thank you for your patience as baseball mitts went unused, homework was not helped, and school meetings were unattended.

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ABSTRACT

Introduction: As more adults are seeking orthodontic treatment, patients with gold or porcelain restorations are seeking orthodontic care. Traditional methods of bonding to these restorations require some type of surface modification. DentStat™ is a compomer that was developed as temporary material for military use in a field environment. There are claims made that it can adhere to any surface. This study attempts to determine if DentStat™ can be used as a bracket adhesive that does not require surface modification in order to bond brackets. **Method**: Victory Series brackets were bonded to type III gold, feldspathic porcelain and bovine enamel by using DentStat™ as the adhesive. When DentStat™ was used as the adhesive, no modification was made to the substrate surface by either etchant or primer per the manufacturers' instructions. The control groups comprised of brackets bonded using Transbond XT™ and the manufacturers protocol of surface preparation for the three surfaces. Brackets were sheared off with an instron machine. Shear bond strength and adhesive remnant index were recorded. There were 15 samples in each group. **Results**: The results show that when Transbond XT™ was used to bond brackets it produced a significantly higher shear bond strength than DentStat™. The average shear bond strengths for brackets bonded to the substrates of gold, porcelain, and enamel with DentStat™ were .0170Mpa, .0974Mpa, and 4.5864Mpa. Those groups bonded with Transbond XT™ for gold, porcelain, and enamel had an average shear bond strength of 2.3216Mpa, 10.7337Mpa, and 8.4312Mpa respectively. The adhesive remnant index showed that no adhesive was left on the substrate surface following the debonding of brackets that used the DentStat™ adhesive.

Conclusions: A clinically sufficient shear bond strength is above 5.9MPa. DentStat™ does not produce a clinically sufficient shear bond strength when bonding brackets to any of the tested surfaces without preparation. Transbond XT™ does produces a clinically sufficient shear bond strength only when bonding to enamel and porcelain using the manufacturer's suggested protocols.

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I. Background

The introduction of acid etching of enamel (Buonocore, 1955) made it possible for the creation of a new generation of orthodontic appliance attachment (Newman, 1965). No longer would fixed orthodontic appliances depend on banding every tooth for comprehensive treatment. As techniques and adhesives improved, direct bonding became more universally accepted (Zachrisson, 1977; Reynolds, 1976). During the next few decades, the pursuit continued for the development of the best technique and the best adhesives for any situation that is encountered in orthodontic bonding (Mandall, 2002). One of the issues that has troubled orthodontics over the years has been the demineralization of enamel around the bracket. The advent of a new dental adhesive in 1971 was presumed to help resolve some of the problems seen with demineralization. Glass ionomer cement was introduced by Wilson and Kent (Wilson and Kent, 1972). Glass ionomer forms a bond directly with the enamel surface of tooth structure as well as forms ionic bonds with stainless steel (Maijer et al, 1988). One of the biggest clinical advantages that came from glass ionomer was the ability to release fluoride to surrounding enamel over time. The glass powder that allows glass ionomer to release the fluoride ion is also available for uptake of fluoride with topical fluoride treatment. Glass ionomer can act as a fluoride reservoir, which helps counteract enamel demineralization during orthodontic treatment (Hamula et al 1993). There are two weaknesses of glass ionomers. They are brittle, which significantly increases the chance of cohesive fractures within the cement.

Additionally, the initial water solubility is high during the first 24 hrs of setting which leads to a weaker initial bond (Phillips, 1985).

Due to the weaknesses of pure glass ionomer cement, a new resin-modified glass ionomer material (RMGI) was developed. This material combined the properties of the glass ionomer with the qualities found in composite resin. There was now a new adhesive material that still had fluoride release, but less solubility and increased resistance to wear and fracture (Sidhu et al, 1995). RMGI were developed so as to be cured by both-acid base reaction and photochemical polymerization. This kept the potential of direct bonding to tooth structure as well as being more hydrophilic than composite resin alone. RMGI's perform well even if there is saliva contamination (Cacciafesta et al, 1998).

In the early 1990's a new class of dental materials became available to the market. Polyacid-modified composite resin, otherwise known as compomers, were to combine even more of the physical properties and esthetics of composite resin with the adhesive properties and fluoride release of glass ionomers. Compomers, besides containing monomer like bisphenylglycidyl dimethacrylate (bisGMA) or tetraethyleneglycol Dimethacrylate (TEGDMA), contain monomers which have an acidic functional group and a reactive glass powder. This allows the compomers to have an initial hydrophobic property like traditional composite resins and set initially by addition polymerization. After the initial set, the hydrophilic portion of the material takes up water to promote an acid-base neutralization reaction between the glass filler and the acid group on the monomer (Eliades et al, 1998). This process allows fluoride to be released from the glass into the matrix, which is then available to be released into the oral environment.

There are numerous properties that make compomers beneficial as a bracket adhesive. Mechanical properties of compomers such as compressive, tensile, and flexure strengths as well as surface hardness are very similar to resin composites. Only fracture toughness was reported to be significantly less in compomers compared to conventional composite resins (Yap et al, 2004). The authors of that study noted that due to reduced resistance of crack propagation, it should not be used in areas of high stress, such as for posterior restorations. Fluoride release is an advantage of compomers. It has been observed that fluoride release occurs for up to 169 hours after the initial set. Although the amount of fluoride released into the environment from compomers is much smaller than that of typical glass ionomer cements, the level of fluoride is sufficient to have an anticariogenic effect (Millar et al 1998). The reservoir of fluoride within the compomer will overtime be depleted, but as with traditional glass ionomers the fluoride level in the compomer can be replenished. With the use of a topical fluoride, a concentrated source of fluoride will cause a localized change in the concentration gradient which will allow fluoride to enter the compomer matrix (Xu et al, 2003). Due to the same acid-base reaction that allows fluoride release, compomers and resin-modified glass ionomers have another property that can protect enamel from decalcification. The acid-base reaction acts as a buffer to an acidic environment. Since caries is known to be caused by the demineralization of enamel by the acid that is found locally from the byproducts of intraoral bacteria, this could be one of the reasons for the anticariogenic effect. In one study, compomer samples were exposed to fresh solutions of lactic acid for 6 weeks. When the lactic acid storage solutions were exposed to samples of compomer, the solutions were buffered toward a neutral pH (Nicholson et al, 1999). Due to advantageous properties of compomers and resin-modified glass ionomers, they make a good choice for orthodontic bracket retention.

According to a Cochrane review by Mandall (Mandall et al, 2002) all of their review papers on comparing RMGI to resin composite adhesives had statistical flaws and few papers have been published on how well compomer adhesives work in orthodontic bonding. A study included in the Cochrane review showed there is no significant difference found in bond failures between compomers and resin adhesive (Millet et al, 2000). Resin adhesives have been shown in the past to have superior bond strengths to glass ionomer cements (Cook et al, 1988), but with the newer resin-modified glass ionomers and compomers, clinical success has been promising. Silverman bonded 150 cases with a resin-modified glass ionomer without using an etchant and showed a success rate of 96.8% bracket retention (Silverman et al, 1995). Although composite resin adhesives have a high bond strength it was found that shear bond strength of 5.9-7.8 is a clinically acceptable range for bonding brackets (Reynolds et al, 1976).

Composite resin adhesives are popular for bracket bonding. One reason that compomers may not have become more popular is that they still need an adhesive primer between the material and the surface to which it is to adhere. This brings no significant advantage as the composite resin adhesive also requires a primer. Since compomers do not store and release as much fluoride or have the direct adhering ability as do glass ionomers, they bring little advantage above that of composite resins. The Naval Institute for Dental and Biomedical Research NIDBR developed DentStat™ **(**NIDBR, Great Lakes, IL), a new material that is categorized as a compomer, but fits in a continuum between resin-modified glass ionomers and compomers. This new material is claimed to have properties that allow it to adhere to ceramic and metal (Ragain JC et al, 2009).

More adults are seeking orthodontic treatment, and many of these adults have teeth restored with porcelain or gold crowns. As these adults seek treatment it is inevitable that more brackets will need to be bonded to porcelain or gold surfaces. The typical procedure for bonding brackets to gold or porcelain requires roughening the surface prior to application of a primer and adhesive. The developers of DentStat™ claim that it can adhere directly to metal and ceramic substrates. If this is true, using DentStat™ as a bracket adhesive might prove to be beneficial in preserving the surface integrity of crowns and in reducing treatment time as the procedure to bond to gold and porcelain will be minimized. DentStat™ will be tested as a bracket adhesive and compared to a current popular resin adhesive (Transbond XT™). Transbond XT™ is proven to work well as an adhesive in bonding brackets to both gold and porcelain. When bonding brackets to gold using a protocol of sandblasting the surface, applying silane, and then using Transbond XT™ primer and adhesive the shear bond strength was 12.54MPa (Shon et al, 2010). In another study brackets were bonded to porcelain surfaces. When the procedure included a surface treatment of sandblasting, application of 9.5% hydrofluoric acid, then application of a porcelain conditioner and Transbond XT™ adhesive, the mean shear bond strength was 11.2MPa (Ajlouni et al, 2005).

DentStat™ has never been tested for bracket bonding. If DentStat™ can provide a clinically acceptable shear bond strength without the use of surface preparation, treatment time will decrease and crowns won't have to undergo a procedure that will leave an unesthetic surface. This combined with the antigcariogenic properties found in compomers would make DentStat™ an extraordinary bracket bonding agent. adhesive Brackets in both groups will be bonded to feldspathic porcelain, type III gold, and enamel.

II. Objectives

A. Overall Objective

The objective of this study is to determine if a new compomer material that was developed as a temporary material for use in military field environments, can be used to effectively bond orthodontic brackets to type III gold, feldspathic porcelain, and enamel without altering the substrate surfaces by use of etchant or primer.

B. Hypothesis

Will DentStat^{TM} bond brackets reliably to the unaltered surfaces of Type III Gold, Feldspathic Porcelain, and Enamel?

III. Materials and Methods

The testing groups compare the shear bond strength of DentStat™, a new compomer material, (NIDBR Great Lakes, Illinois), against a popularly used orthodontic composite resin adhesive, Transbond XT™ (3M Unitek Monrovia, California), as they are used to bond orthodontic brackets to gold, porcelain, and enamel. Both adhesives will be used to bond Victory Series MBT™.022 twin maxillary right central incisor brackets (3M Unitek Monrovia, California) to bovine incisors, type III gold and feldspathic porcelain. Each group will contain 15 samples.

With the control groups, Transbond XT™ was applied utilizing the protocol from the manufacturer for gold, porcelain, and enamel. The test groups used DentStat™ with surfaces that were otherwise untreated.

50 bovine incisors (Animal Technologies Inc., Tyler, TX) were stored in deionized water. The roots were cut off and the facial surfaces were flattened using a diamond wheel. Incisors were carefully examined for any dentin exposure. The incisors that had any dentin exposure or any flattened surface that was too small to accommodate the orthodontic bracket were discarded. 30 incisors were placed flat surface down inside a ¾ inch PVC pipe coupler. Then, mounting stone was poured around the incisor to secure it within the PVC matrix. These substrate samples were then polished with 500 grit sand paper, by rubbing the enamel surface against the sand paper 5 times in a distal mesial direction and then 5 times incisal cervical direction. The completed samples were then ready for bonding brackets.

For the control group the enamel surfaces were rinsed with water for 3 seconds. The samples were air dried and then Transbond Plus™ self etching primer (3M Unitek Monrovia, California) was activated for 5 seconds and then rubbed on the enamel surface for 3 seconds. A gentle stream of air was used to thin the primer for 3 seconds. Transbond XT™ (3M Unitek Monrovia, California) was then placed on a bracket and the bracket was pressed firmly against the enamel surface. Excess adhesive was removed with an explorer. The ValoOrtho LED light (Ultradent, South Jordan, Utah) was used to cure the adhesive for 5 seconds on the incisal edge of the bracket and 5 seconds on the cervical side of the bracket on the standard power mode which delivers $1000mW/cm^2$. The curing light tip touched both bracket and flat substrate so as to keep curing light equidistant for all samples during curing.

For the test group, the samples were rinsed with water for 3 seconds and dried, as was the control group.

DentStat™ was weighed out so that there was a 3:1 powder to liquid ratio. Enough powder and liquid was used to provide enough material to bond three brackets. After mixing the DentStat™, there was only enough time to bond three brackets before the material started to cure. The DentStat™ was mixed and placed on the bracket. The bracket was placed firmly against the enamel sample. The excess was removed with an explorer and a microbrush. The sample was then cured in the same manner as with the control groups.

The Gold (Firmilay Type III, Jelenko, San Diego, CA) samples were made from the 13x8x1.5mm plates that came from the factory. These plates were placed polished side down inside the PVC matrix. Mounting stone was poured around these plates to secure them inside the matrix. The gold plates were polished with green polishing tip for 10 secs.

For the control group, gold plates were air abraided with Etchmaster™ (Margate, FL) from a distance of 5+/- 1mm for 3 seconds with 50micron aluminum oxide powder then rinsed with water for 5 seconds and then air dried. Adper™ Scotchbond™ multi-purpose primer (3M ESPE, St Paul, MN) was applied to the substrate and air thinned for 5 seconds. Adper™ Scotchbond™ multi-purpose adhesive was then applied to the gold substrate and light cured for 10 seconds. A bracket containing Transbond XT™ adhesive was placed on the substrate. Excess adhesive was removed and the sample was cured using the same protocol as used with the enamel samples. The test group was not air abraided but was rinsed and air dried. The brackets were bonded directly to the polished gold using DentStat™ with the same procedure as was used with the enamel substrates.

The Porcelain samples were made from Vitablocs Mark II Classic Shade A2 (Vident, Brea, California).Vitablocs were used in the sintered form as they come from the factory. The Vitablocs were placed flat into a PVC matrix surface and then mounting stone was poured around the samples to secure their position in the matrix. For the control group the porcelain samples were air abraided in the same manner that the gold control group was. These samples were rinsed and air dried then RelyX™ Ceramic Primer (3M ESPE, St Paul, MN) was applied to the porcelain substrates. Transbond XT™ primer was then applied in a thin layer to the samples. Transbond XT™ adhesive was placed on the bracket and then the bracket was firmly pressed against the substrate. The excess adhesive was removed and the sample was light cured according to the process for the previous groups. The test group was not air abraided but was rinsed and air dried. The brackets were bonded directly to the sintered porcelain as it came from the factory using DentStat™ and the same procedure as was used with the enamel and gold substrates for bonding.

All samples were immediately stored in deionized water for 24 hours at 37degrees C. After 24 hours, samples were removed from the incubator and the samples were put in a jig (Ultradent, South Jordan, UT) that held the flat surface of the sample vertical. Enamel samples were loaded in to the jig so as to have the incisal edge of the enamel substrate facing upward, and all samples were loaded so that the incisal edge of the bracket was facing upward. The jig was placed into a universal testing machine (Instron 5943R9153, Norwood, MA). A straight blade was mounted onto the 1 Kilonewton load cell. Prior to the initiation of the test the blade was placed against the flat surface of the sample and with a crosshead speed of 1mm/min it moved perpendicular against the occlusal surface of the bracket base until bond failure. Based on maximum force at the time of the failure, shear bond strength was determined for each sample in MPa (load/area of bracket base).

Each specimen was examined for mode of failure under a 10x microscope using the adhesive remnant index (ARI) for each sample. A grade was given for each category. If all adhesive remains on the bracket a rank of 0 is given. If more than 50% of the adhesive is left on the bracket a rank of 1 is given. If less than 50% of the adhesive is left on the bracket then a rank of 2 is given for the sample, and if all of the adhesive is left on the sample a rank of 3 is given.

At conclusion of this study all bovine teeth were collected and disposed of as biohazardous waste in accordance with occupational Safety and Health Administration (OSHA) regulations and standard military protocol. Standard safety precautions were instituted while handling all teeth.

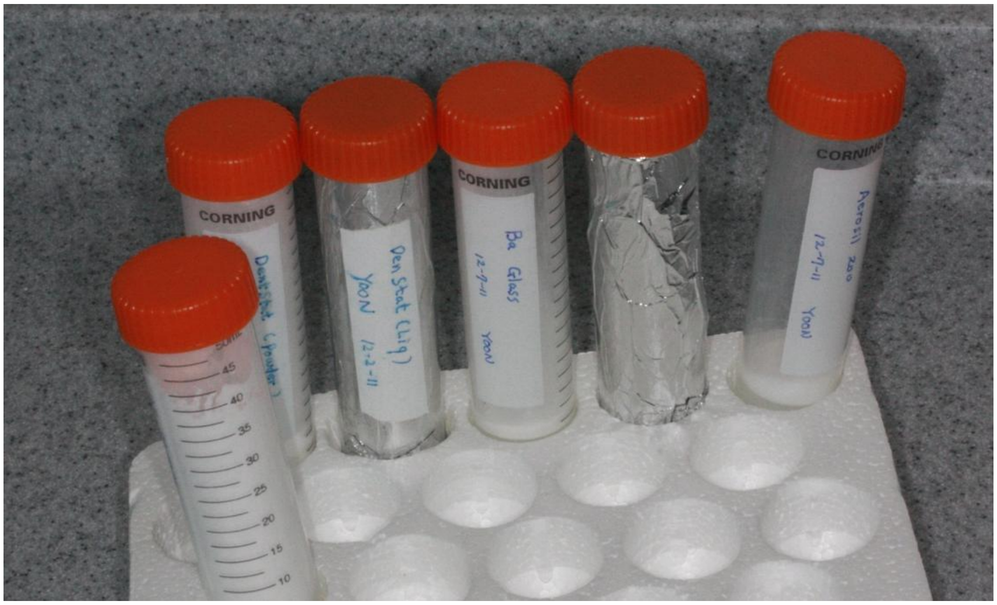


Figure 1. Materials that were mixed to make the DentStat

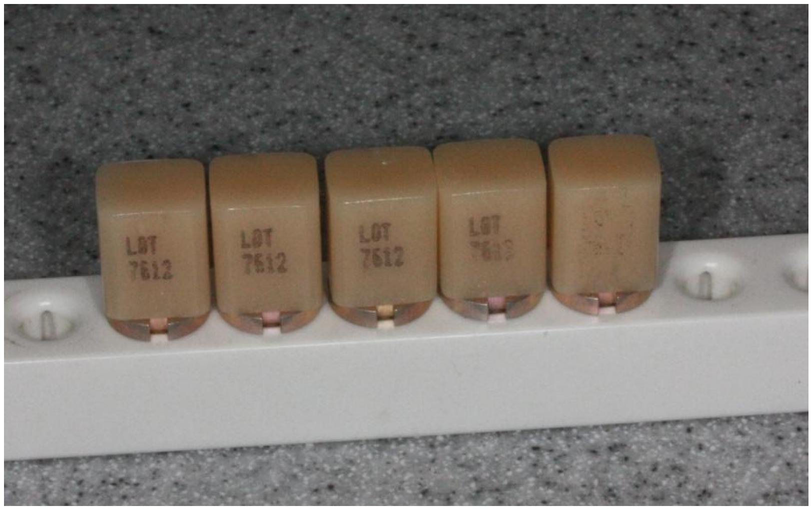


Figure 2 Porcelain Vitablocs before being placed in the PVC matrix

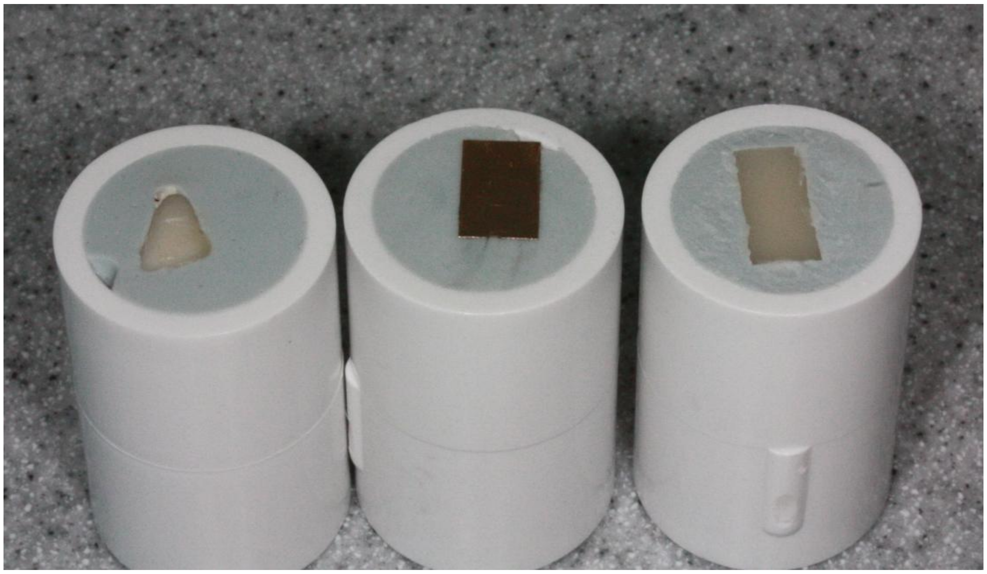


Figure 3 Samples of the enamel, gold, and porcelains substrates as they were mounted in the PVC matrix.

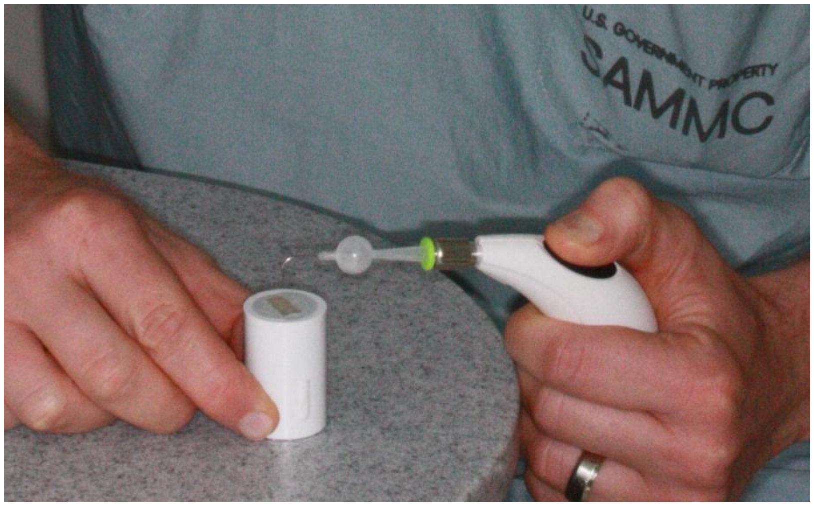


Figure 4 Air abrasion technique

Figure 5 DentStat must be mixed thoroughly.

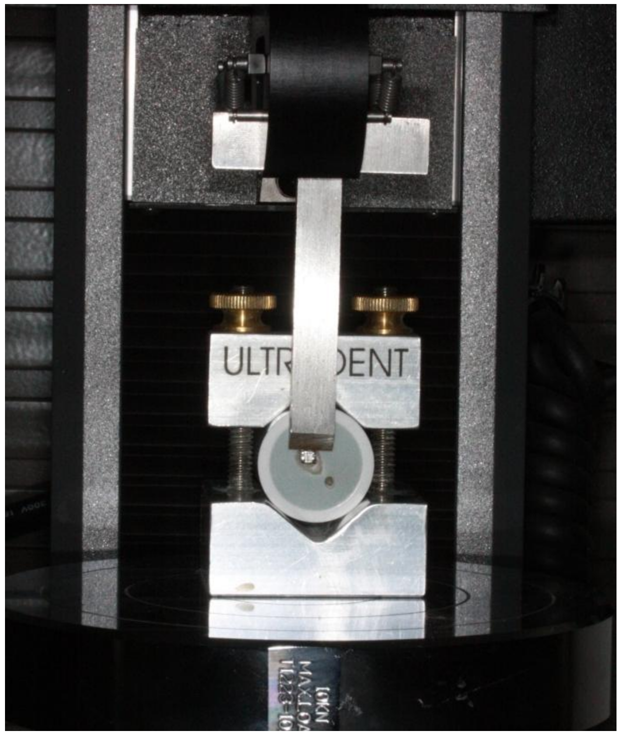


Figure 6 The setup before the initiation of the test in the instron.

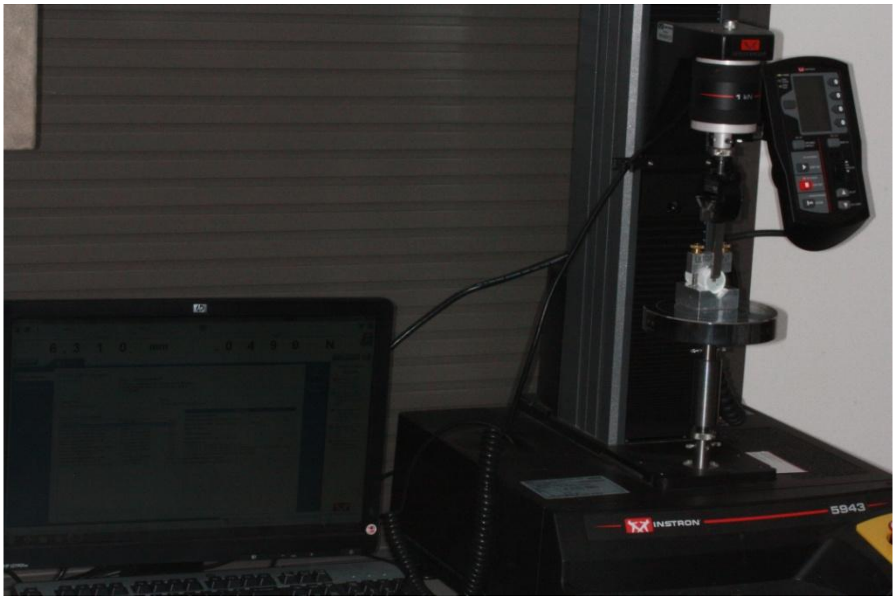


Figure 7 Instron setup

Figure 8 Each bracket base is carefully examined under a microscope to assess the adhesive remnant index.

IV. Statistical Analysis:

A power analysis was performed to determine that if 15 samples were used there would be sufficient strength in this study.

The typical statistical analyses that are used to show differences between shear bond strength groups include the use of parametric analyses such as T-tests and ANOVAs. With the current study, a new material was used to bond brackets. DentStat™ was not developed for use with bonding brackets nor made any claim to be able to. As DentStat™ was used to bond brackets directly to polished gold and porcelain, several brackets debonded before being placed in the Instron testing machine. These samples were counted as zero shear bond strength. The standard deviations for these groups were thus large and the variances in the results of shear bond strength across the groups being tested were too different to use the parametric statistics. When the variance of the results is different between the groups a non-parametric test must be employed to determine differences. The Kruskal Wallis test was used to determine if there was a difference between the shear bond strength within the groups bonded by either DentStat™ or Transbond XT™. There was a difference shown and then a post hoc test was run using the Mann-Whitney U statistic. The statistical analysis used to determine differences between all shear bond strength groups was the Mann-Whitney U test. Since there were nine possible different comparisons made between the bonding systems the Bonferroni correction was utilized to bring the level for statistical significance to an alpha of .006. The adhesive remnant index creates non-parametric data. The statistic used to infer a difference between the groups of adhesive remnant index was the Kruskal-Wallis with the Bonferroni Correction which brought the alpha to .0167.

V. Results

Results were collected after subjecting the bonded brackets to shearing force in the Instron universal testing machine. As the blade attached to the load cell moves downward, it pushes against the occlusal surface of the bracket at a cross-head speed of 1mm per minute. The force on the load cell is recorded as the blade continues its downward movement. Once there is a significant drop in the force needed for the blade to continue downward, the blade stops and the load cell records the maximum force applied. Brackets were then manually checked to see if debonding had occurred or if the load cell registered a break in the excess adhesive that was on the surface of the substrate. When it was determined the break was caused by the debonding of the bracket then the maximum force was recorded. This force in newtons was then divided by the surface area of the bracket base (10.1935mm^2) to give the shear bond strength for that sample in mega pascals (MPa). The shear bond strength for all samples are given along with the average shear bond strength and the standard deviation for each group. Table 1, 2.

Shear Bond MPa of DentStat

Sample #	Gold	Porcelain	Enamel
1	0.0177	0.0069	2.5275
2	0.0064	0.0500	5.0664
3	0.0000	0.1482	3.2323
4	0.0359	0.0000	8.2924
5	0.0371	0.0809	4.7482
6	0.0000	0.0459	5.8302
7	0.0198	0.1848	4.8683
8	0.0102	0.2623	2.8626
9	0.0000	0.0000	4.4198
10	0.0000	0.0980	6.0849
11	0.0059	0.2110	2.6606
12	0.0852	0.0459	2.5884
13	0.0237	0.0405	4.9769
14	0.0000	0.1778	7.2974
15	0.0135	0.1081	3.3403
	Gold	Porcelain	Enamel
Average	0.0170	0.0974	4.5864
St Dev	0.0227	0.0824	1.7666

Table No. 1 Shear Bond strength when brackets were bonded with DentStat.

Shear Bond Strength of Transbond XT

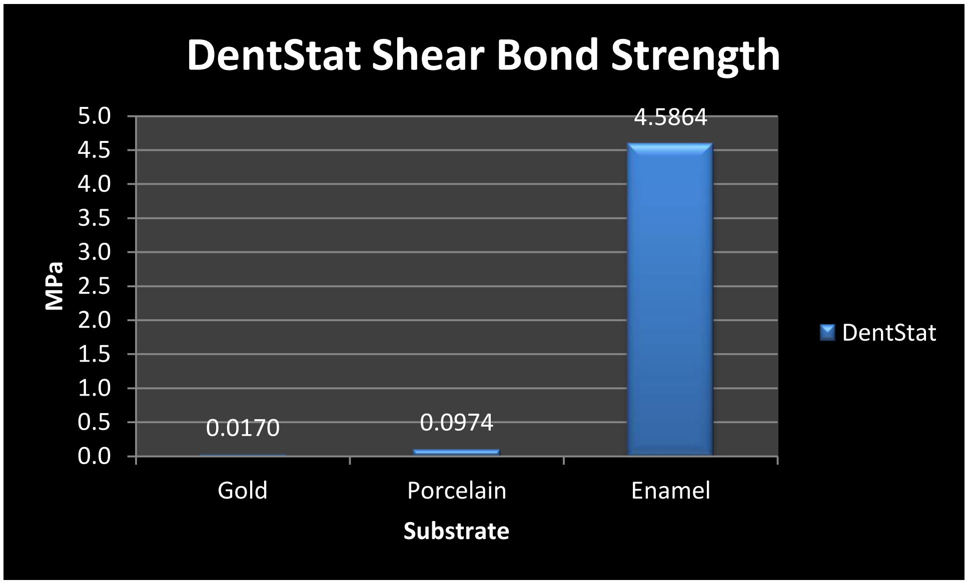
Sample #	Gold	Porcelain	Enamel
1	1.5374	11.1404	8.5945
2	2.7522	8.6553	8.7343
3	1.0647	11.3874	8.3749
4	2.3179	10.8978	7.3610
5	2.3415	7.1944	8.7049
6	2.0051	10.7700	7.7340
7	3.1503	11.8221	8.6835
8	3.3733	12.0589	6.0597
9	2.7407	10.6590	8.4264
10	3.2683	10.2315	7.4046
11	0.9630	10.8781	12.1823
12	1.5416	11.9046	11.5683
13	2.4934	12.6397	5.9003
14	2.9823	12.8900	7.0828
15	2.2921	7.8766	9.6559

	Gold	Porcelain	Enamel
Average	2.3216	10.7337	8.4312
St Dev	0.7684	1.6584	1.7363

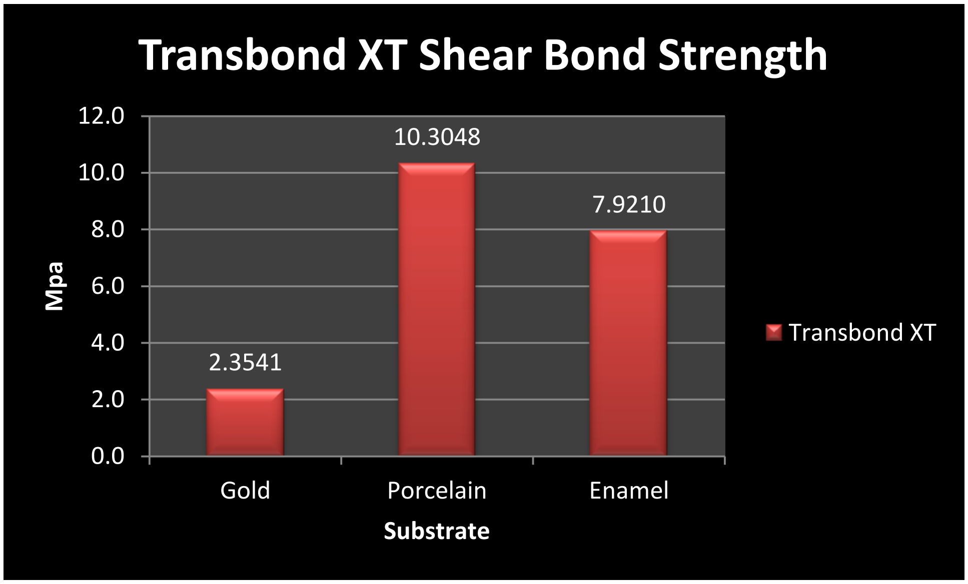
Table No. 2 Shear Bond strength when brackets were bonded with Transbond XT

When bonding brackets to gold using DentStat™ there were 5 brackets that debonded before they were tested. Also, when bonding brackets to porcelain using DentStat™, 2 brackets debonded before testing. These samples were recorded as zero shear bond strength. The bond failures as well as the low shear bond strength led to a low average shear bond strength and high standard deviation for these two groups with .0170(.0227)MPa and .0974(.0824)MPa for gold and porcelain respectively. Notice that the standard deviation for brackets bonded to gold is higher than the actual average shear bond strength. The data sets that came from all of the control groups and from the enamel test group were fairly tightly grouped for shear bond tests showing the extreme care in maintaining protocol integrity.

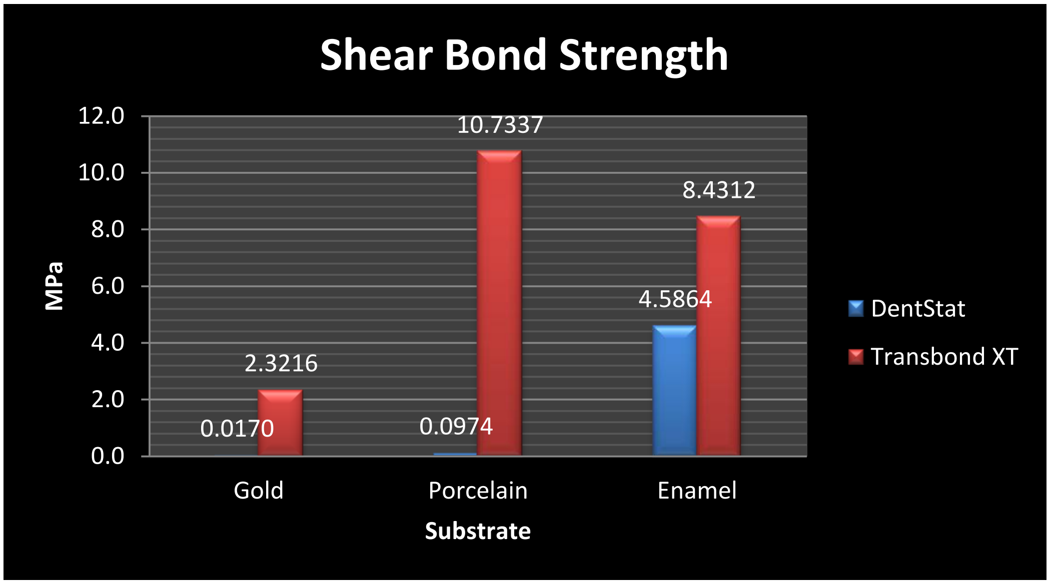
It is important to ascertain whether there was a difference between shear bond strengths in the groups of different surfaces, but using the same bonding material. Because of the large inter-group variance the Kruskal-Wallis test was used to show the difference between the groups using the same bonding system for both DentStat™ and Transbond XT™. It was shown that within the DentStat™ groups that there was a statistically significant difference. In order to find where the difference was, the Mann-Whitney U post hoc test was performed to show that there were differences between all groups. The average shear bond strengths for brackets bonded to the substrates of gold, porcelain, and enamel with DentStat™ were .0170Mpa, .0974Mpa, and 4.5864Mpa respectively (Graph1). Bonding to enamel with DentStat™ had the highest shear bond strength followed by porcelain, and then gold. Using the same statistics as above for the Transbond XT™ groups it was shown that there was a statistically significant difference between all groups. Those groups bonded with Transbond XT™ for gold, porcelain, and enamel had an average shear bond strength of 2.3216Mpa, 10.7337Mpa, and 8.4312Mpa respectively (Graph 2). This shows that within the Transbond XT™ group that porcelain had a significantly higher shear bond strength than enamel and enamel was significantly higher than gold.


DentStat Shear Bond Strength
MPa
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0170
0.0974
4.5864
Gold
Porcelain
Enamel
Substrate
DentStat

Graph 1


Transbond XT Shear Bond Strength
Mpa
12.0
10.0
8.0
6.0
4.0
2.0
0.0
2.3541
10.3048
7.9210
Gold
Porcelain
Enamel
Substrate
Transbond XT

Graph 2



Shear Bond Strength
MPa
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.0170
2.3216
0.0974
10.7337
4.5864
8.4312
Gold
Porcelain
Enamel
Substrate
DentStat
Transbond XT

Graph 3

The differences between the Shear bond strength of DentStat™ and Transbond XT™ are shown by using the Mann-Whitney U test followed by the Bonferroni correction (graph 3) It was found that there is statistically significant differences with all comparisons between DentStat and Transbond XT™ having a p<.006. With this information we can infer that the using Transbond XT™ and their manufacturer's suggested protocol shows a statistically significant higher shear bond strength than DentStat™ with every substrate. Looking at the difference when bonding to gold substrate, DentStat™ had an average shear bond strength of .0170MPa and Transbond XT™ showed 2.3216MPa. The difference is 2.3046MPa, which in terms of shear bond strength is not large, but this difference also shows that the Transbond XT™ system delivered 137 times more strength than DentStat™. For porcelain samples the average shear bond strength was .0974MPa when using DentStat™ whereas it was 10.7337MPa when using Transbond XT™. This shows a 10.6363 MPa difference or 110 times stronger bond when using Transbond XT™. For the enamel samples DentStat™ showed more promise as the shear bond strength was 4.5864MPa and when bonding with Transbond XT™ an 8.4312MPa bond strength showed that the difference between the two systems was 3.8448MPa and was only 1.8 times stronger. All averages and standard deviations, as well as statistically significant differences are found in Table 3.

MPa Averages and Standard Deviations

	DentStat		Transbond XT	
Gold	0.017(0.022)	aA	2.32(0.77)	aB
Porcelain	0.097(0.082)	bA	10.73(1.66)	cB
Enamel	4.59(1.77)	cA	8.43(1.74)	bB

All Groups with the same lower case letters per column or upper case letters per row are not significantly different

Table 3.

Adhesive Remnant Index for DentStat Samples

Sample #	Gold	Porcelain	Enamel
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	0	0	0
14	0	0	0
15	0	0	0

	Gold	Porcelain	Enamel
Average	0.0	0.0	0.0
St Dev	0.0	0.0	0.0

Table 4 Adhesive Remnant Index for DentStat Samples.

Adhesive Remnant Index for Transbond XT Samples

Sample #	Gold	Porcelain	Enamel
1	0	2	2
2	0	3	2
3	0	1	1
4	0	1	1
5	0	1	2
6	0	1	2
7	0	1	1
8	0	1	3
9	0	1	3
10	0	1	3
11	0	1	1
12	0	1	1
13	0	1	3
14	0	1	2
15	0	2	1

	Gold	Porcelain	Enamel
Average	0.0	1.3	1.9
St Dev	0.0	0.6	0.8

Table 5 Adhesive Remnant Index for Transbond XT Samples

After determining the shear bond strength, it was important to evaluate the mode of failure. The adhesive remnant index shows whether there is a trend in how the bond fails. This shows whether the failure of the bond is due to an adhesive failure at the substrate interface, or if it is a cohesive fracture within the material or if the bond of the adhesive to the bracket is the cause. The raw data is shown in tables 4 and 5. When bonding with DentStat™ there was no statistical significant difference found between the ARI found for all groups. From these results it is apparent that the mode of failure when DentStat™ is used for bonding is found between the adhesive and the substrate. There was also no difference found between all of groups bonded with DentStat™ and the group which used Transbond XT™ to bond to gold. All of the adhesive was left on the bracket leading to the conclusion that the bond is weakest between the substrate and the adhesive. When bonding with Transbond XT™, there was a statistically significant difference found between the gold and porcelain groups, as well as the gold and enamel groups, but there was no difference found between the porcelain and enamel groups. There appears to be a trend with using Transbond XT™ that shows more adhesive was left on brackets bonded to porcelain than with those bonded to enamel, but because of the use of the Bonferroni correction there is no statistical difference between the two groups. Under normal statistical situations the p value limit for statistical significance shows that there is a difference with anything less than .05, but because of the use of the Bonferroni correction the alpha value was reduced to .0167 meaning that any p value not less than that would not be a statistically significant difference.

VI. Discussion

The prospect of having an adhesive material that could be used to bond brackets to gold and porcelain surfaces without having to physically alter the polished surfaces of the dental prosthesis would be of great benefit. Such a material would allow brackets to be bonded to finished esthetic anterior restorations without having to deglaze the surface. This would allow a more predictable post-treatment return to its original luster. With the potential possibility that DentStat™ could adhere better to metals and ceramics than previously developed bracket adhesives, the decision was made to test how well the bond strength of this adhesive compared to that of an adhesive that is readily used by orthodontists.

Comparing the shear the bond strength from DentStat™ on the unprepared surfaces to the bond strength found when using Transbond XT™ with the manufacturer's protocol, produced a statistically significant difference. Using Transbond XT to bond brackets provides significantly higher shear bond strengths. Although the shear bond strengths were higher when using Transbond XT™ that does not necessarily translate to clinical relevance. For Transbond XT™ both gold and porcelain surfaces were air abraided in order to provide some kind of mechanical retention. This air abrasion would remove the polished finish from the restoration which after debonding the orthodontic appliances would leave an unesthetic result. This is an undesirable result that would potentially require replacement, or leave the patient with a less than desirable finish even after polishing. It was found that even with the air abrasion when brackets were bonded to gold with the Transbond XT™ protocol, the average resultant shear bond strength was only 2.32 MPa. It would be fair to question the technique for this control group when using the manufacturer's suggested protocol, since the shear bond strength was lower than what is clinically acceptable for bonding brackets. According to Reynolds (Reynolds et al, 1976), shear bond strength of brackets needs to be at least 5.9MPa-7.8MPa in order to have sufficient strength for clinical purposes. In a previous study, when bonding brackets to gold using a protocol of sandblasting the surface, applying silane, and then using Transbond XT™ primer and adhesive the shear bond strength was between 5.58-12.54MPa (Shon et al, 2010). This deficiency of shear bond strength in this study could be due to the fact that silane was not part of the suggested protocol. Silane coupling is used to promote a chemical bond between resin and alloy surfaces (Nergiz et al. 2004). Adding silane to the process could have possibly produced clinically sufficient strength. Fortunately, it is rare to find anterior restorations fabricated from gold. If gold is used today in restorations, it is more likely to be used with molars for full crowns, which can easily be banded which eliminates the need for bonding brackets.

More often than not anterior crowns and veneers are made from porcelain. The results collected after using Transbond XT™ to bond brackets to porcelain provided the highest shear bond strength of all of the test groups. This group achieved a shear bond strength of 10.73MPa. This compares closely to a previous study that used a similar protocol and had the mean shear bond strength of 11.2MPa (Ajlouni et al, 2005). A potential variance could come from the difference in the type of porcelain used in this study. In this study the porcelain is homogenous throughout the cerec block, whereas traditional porcelain restorations have many layers of porcelain within the surface. Nonetheless, it has been known for quite some time that brackets bonded to porcelain have a higher shear bond strength (Barbosa et al, 1995, and Kao et al 1988). When it came to bonding to enamel, Transbond XT^{TM} provided a predictable mean shear bond strength of 8.43MPa which although is significantly less than when bonding to porcelain it is also clinically acceptable.

The data from the adhesive resin index for all of the control groups, showed that Transbond XT^{TM} did not bond to Gold since all of the adhesive remained on the bracket. With the porcelain group, although it had significantly higher shear bond strengths, it was interesting that there appeared to be less adhesive on the substrate surface than on the bracket in comparison with the enamel substrate group. It was found that after the bonferroni correction that there was no statistical significance, but there was an observable trend that less adhesive was left on porcelain. This doesn't compare well with a study done by Franzotti (Franzotti, et al, 2002) who found that when bonding brackets to porcelain the majority of the adhesive remained on the porcelain surface. The difference could be related to any number of differences between the studies including different types of brackets with dissimilar bases. With that exception and the exception of the gold substrate group having a shear bond strength a little lower than would have been expected the control groups showed results that seem fairly typical.

As DentStat™ is the new material, there were no expectations as to how it would perform as a bracket bonding agent. There were two sets of Data collected in this study. One set was to determine shear bond strength of both the test and control adhesive on each of the surfaces and the other to show the mode of failure for the debonded brackets. Examining the mode of failure showed one of the greatest strengths of DentStat™. When observing all of the substrates surfaces after debonding, the brackets that were bonded with DentStat™, no adhesive was left on the surface. All of the adhesive was left on the bracket leaving the surfaces with their original sheen. One of the objectives of the study was to determine if DentStat™ could bond brackets to porcelain and gold without having to alter the surface of the restoration. Unfortunately the ease with which the adhesive debonded from the surface as well as the lack of creating surface roughness in the protocol likely led to the lower shear bond strength of the brackets that were bonded with DentStat™. The average shear bond strength for brackets bonded to gold and porcelain using DentStat™ was .0170MPa and .0974MPa respectively. This data was skewed towards a lower average shear bond strength, because after allowing the samples to sit in 37˚C deionized water for 24 hours, five of brackets bonded to gold and 2 of the brackets bonded to porcelain debonded before a testing load could be applied. For statistical purposes these had to be recorded as zero shear bond strength creating a lower mean shear bond strength. Although the claim can be made that DentStat™ bonds to both gold and porcelain without surface modification, this study's results show that the shear bond strength provided is clinically insufficient.

When DentStat^{TM} was used to bond brackets to enamel the average shear bond strength was 4.59MPa. Using the DentStat^{TM} material without having any surface preparation by acid etching or using a primer came close to delivering clinically sufficient strength for bracket bonding. This compares fairly well with other studies where a resin modified glass ionomer or a compomer was used as an adhesive without any other surface preparation procedure producing strengths of 3.39MPa and 3.21MPa (Sethusa et al, 2009; Meehan et al, 1999).

The popularity of testing compomers and RMGI grew towards the end of the 1990s and seemed to die in the early 2000s. There were some good reasons to pursue the use of these types of materials for bonding brackets. It was always the goal to reduce bonding time, and if an orthodontist could bond brackets without having to use a primer or an etchant, it would reduce not only time, but also material inventory. The promise of having a material that could act as a fluoride reservoir and prevent decalcification was also appealing. Unfortunately the bond strength of the glass ionomer type materials was never as strong as the resins with a separate primer. Because of their consistently lower shear bond strengths some investigators thought that it would be appropriate to use these with ceramic brackets, which at the time had the problem of providing too much bond strength. When bonding ceramic brackets with the resin adhesive systems, the bond strength was so strong that there were reports of enamel tears. Further investigations found that there was good evidence for the use of these glass ionomer type products with ceramic brackets. Later, bracket companies fabricated their brackets in such a way so that they could be more easily debonded, usually by having a weakness in the base causing a fracture in the bracket. This eliminated the need to have an adhesive that was not as strong.

DentStat™ was developed to be a field-expedient temporary material for the military. This material could definitely serve its purpose as a temporary material for use in a deployed setting. More adults are receiving orthodontic care and members of the military are receiving orthodontic care. Many times it is not convenient to debond orthodontic appliances when service members undergoing orthodontic treatment are required to deploy to remote assignments. As the jobs of our service members can be physically demanding, the deployed military personnel may have a bracket debond and may not have the time or convenience needed to return to a location that might have the supplies needed to properly fix a debonded bracket, but there may be a general dentist nearby who could safely and effectively use DentStat™ to rebond a bracket temporarily. This could potentially prevent movement of military personnel through a dangerous war zone.

DentStat™ has been investigated for many uses and now has been tested for the use of bonding brackets. Although it does bond to porcelain, metal, and enamel, the shear bond strength tests showed that using DentStat™ as a bracket bonding agent would not be a wise choice if there are alternative adhesives available. It can however be used to bond brackets to enamel if no other material is available and a temporary solution was needed. This study did not show any data of ceramic brackets bonded to enamel surfaces with DentStat™. In other studies, it was shown that similar glass ionomer based materials showed sufficient shear bond strengths when bonding ceramic brackets to enamel surfaces when using a primer. (Cacciafesta et al,1998). This is an area that could be investigated by further studies with DentStat^{TM}. If DentStat^{TM} performed well when bonding ceramic brackets to enamel, one good use for this material would be for bonding brackets in patients with bad hygiene that demanded ceramic brackets. That scenario is not unlikely with today's patients. This would allow for the lower shear bond strength that is a benefit for bonding ceramic brackets, and act as a fluoride reservoir to help prevent decalcification.

No matter what the scenario, there are still drawbacks for bonding up entire cases with this material how it is presently formulated. Due to the fact that DentStat^{TM} must be mixed to initiate a chemical cure that sets within a couple of minutes, during this study a maximum of three brackets could be bonded at any one time. The formula would have to be premixed and strictly light cured. Being that the current formula DentStat^{TM} is dual cure, there is a potential practical use for it in orthodontics. Due to the inability of light to effectively reach all surfaces behind a seated orthodontic band, band cements require a dual cure system. There are already resin modified glass ionomer and compomer cements used as band cements. This is an area of orthodontics where DentStat^{TM} would likely prove to be useful, and studies should be done to test this material as a band cement.

VII. Conclusions

1. This study showed that the null hypothesis that there is no difference between the shear bond strength of bonding brackets to gold, porcelain, and enamel, using either DentStat™ or Transbond XT™, was rejected.
2. It was found that Transbond XT™ has statistically significant higher shear bond strengths than DentStat™ when bonding brackets to gold, porcelain, and enamel.
3. Using the protocols in this study, Transbond XT™ provided clinically sufficient shear bond strengths when bonding brackets to enamel and porcelain, but not when bonding brackets to gold.
4. When surfaces are unaltered by primer or etchant, DentStat™ provided clinically insufficient shear bond strength for gold, porcelain and enamel. The shear bond strength when using DentStat™ to bond brackets to an unaltered enamel surface was only 1MPa short of what would be considered clinically acceptable.
5. The adhesive remnant index showed that after debonding no DentStat™ material was found on the substrate surface.

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Sample Size For Comparing Two Means

Input Data

Confidence Interval (2-sided)	95%		
Power	80%		
Ratio of sample size (Group 2/Group 1)	1		
	Group 1	**Group 2**	**Mean difference[1]**
Mean	8.98	12.54	-3.56
Standard deviation	2.44	2.45	
Variance	5.9536	6.0025	
Sample size of Group 1	8		
Sample size of Group 2	8		
Total sample size	16		

Sample Size For Comparing Two Means

Input Data

Confidence Interval (2-sided)	95%		
Power	90%		
Ratio of sample size (Group 2/Group 1)	1		
	Group 1	**Group 2**	**Mean difference[1]**
Mean	8.98	12.54	-3.56
Standard deviation	2.44	2.45	
Variance	5.9536	6.0025	
Sample size of Group 1	10		
Sample size of Group 2	10		
Total sample size	20		

Kruskal Wallis Dentstat

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
MPA	45	1.5669	2.3787	.00	8.29
MATERIAL	45	2.00	.83	1	3

Kruskal-Wallis Test

Ranks

	MATERIAL	N	Mean Rank
MPA	**1**	15	10.53
	2	15	20.47
	3	15	38.00
	Total	45	

Test Statistics(a,b)

	MPA
Chi-Square	33.767
df	2
Asymp. Sig.	.000

a Kruskal Wallis Test

b Grouping Variable: MATERIAL

DentStat Mann-Whitney Test

Ranks

	MATERIAL	N	Mean Rank	Sum of Ranks
MPA	1	15	10.53	158.00
	2	15	20.47	307.00
	Total	30		

Test Statistics(b)

	MPA
Mann-Whitney U	38.000
Wilcoxon W	158.000
Z	-3.110
Asymp. Sig. (2-tailed)	.002
Exact Sig. [2*(1-tailed Sig.)]	.001(a)

a Not corrected for ties.

b Grouping Variable: MATERIAL

DentStat Mann-Whitney Test

Ranks				
	MATERIAL	N	Mean Rank	Sum of Ranks
MPA	1	15	8.00	120.00
	3	15	23.00	345.00
	Total	30		

Test Statistics(b)	
	MPA
Mann-Whitney U	.000
Wilcoxon W	120.000
Z	-4.677
Asymp. Sig. (2-tailed)	.000
Exact Sig. [2*(1-tailed Sig.)]	.000(a)
a Not corrected for ties.	
b Grouping Variable: MATERIAL	

DentStat Kruskal-Wallis Test

Ranks

	MATERIAL	N	Mean Rank
MPA	2	15	8.00
	3	15	23.00
	Total	30	

Test Statistics(a,b)

	MPA
Chi-Square	21.784
df	1
Asymp. Sig.	.000

a Kruskal Wallis Test

b Grouping Variable: MATERIAL

Kruskall Wallis Transbond

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
MPA	45	7.1621	3.8610	.96	12.89
MATERIAL	45	2.00	.83	1	3

Kruskal-Wallis Test

Ranks

	MATERIAL	N	Mean Rank
MPA	**1**	15	8.00
	2	15	35.07
	3	15	25.93
	Total	45	

Test Statistics(a,b)

	MPA
Chi-Square	32.975
df	2
Asymp. Sig.	.000

a Kruskal Wallis Test

b Grouping Variable: MATERIAL

Transbond Mann-Whitney Test

Ranks

	MATERIAL	N	Mean Rank	Sum of Ranks
MPA	1	15	8.00	120.00
	2	15	23.00	345.00
	Total	30		

Test Statistics(b)

	MPA
Mann-Whitney U	.000
Wilcoxon W	120.000
Z	-4.666
Asymp. Sig. (2-tailed)	.000
Exact Sig. [2*(1-tailed Sig.)]	.000(a)

a Not corrected for ties.

b Grouping Variable: MATERIAL

Transbond Mann-Whitney Test

Ranks				
	MATERIAL	**N**	**Mean Rank**	**Sum of Ranks**
MPA	**1**	15	8.00	120.00
	3	15	23.00	345.00
	Total	30		

Test Statistics(b)	
	MPA
Mann-Whitney U	.000
Wilcoxon W	120.000
Z	-4.666
Asymp. Sig. (2-tailed)	.000
Exact Sig. [2*(1-tailed Sig.)]	.000(a)
a Not corrected for ties.	
b Grouping Variable: MATERIAL	

Transbond Kruskal-Wallis Test

Ranks

	MATERIAL	N	Mean Rank
MPA	2	15	20.07
	3	15	10.93
	Total	30	

Test Statistics(a,b)

	MPA
Chi-Square	8.073
df	1
Asymp. Sig.	.004

a Kruskal Wallis Test

b Grouping Variable: MATERIAL

Gold Mann-Whitney Test

Ranks

	MATERIAL	N	Mean Rank	Sum of Ranks
MPA	1	15	8.00	120.00
	2	15	23.00	345.00
	Total	30		

Test Statistics(b)

	MPA
Mann-Whitney U	.000
Wilcoxon W	120.000
Z	-4.677
Asymp. Sig. (2-tailed)	.000
Exact Sig. [2*(1-tailed Sig.)]	.000(a)
a Not corrected for ties.	
b Grouping Variable: MATERIAL	

Porcelain Mann-Whitney Test

Ranks				
	MATERIAL	**N**	**Mean Rank**	**Sum of Ranks**
MPA	**1**	15	8.00	120.00
	2	15	23.00	345.00
	Total	30		

Test Statistics(b)	
	MPA
Mann-Whitney U	.000
Wilcoxon W	120.000
Z	-4.667
Asymp. Sig. (2-tailed)	.000
Exact Sig. [2*(1-tailed Sig.)]	.000(a)
a Not corrected for ties.	
b Grouping Variable: MATERIAL	

Enamel Mann-Whitney Test

Ranks				
	MATERIAL	**N**	**Mean Rank**	**Sum of Ranks**
MPA	**1**	15	8.73	131.00
	2	15	22.27	334.00
	Total	30		

Test Statistics(b)	
	MPA
Mann-Whitney U	11.000
Wilcoxon W	131.000
Z	-4.210
Asymp. Sig. (2-tailed)	.000
Exact Sig. [2*(1-tailed Sig.)]	.000(a)
a Not corrected for ties.	
b Grouping Variable: MATERIAL	