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COMPARISON OF ORTHODONTIC ADHESIVES FOR BONDING OF CERAMIC BRACKETS TO CAD/CAM PROVISIONAL CROWNS

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STRUCTURED ABSTRACT

Introduction: This study was designed to compare the shear bond strength (SBS) of four commonly-used orthodontic adhesive systems used for bonding ceramic brackets to Computer-Aided Design/Computer-Aided Milling (CAD/CAM) Poly Methyl Methacrylate (PMMA) provisional crowns.

Methods: The surfaces of PMMA blocks (Ivoclar Vivadent Inc.) were prepared prior to bonding 80 ceramic brackets (3M Unitek Clarity Advanced MBT with 0.022-inch slot) using four adhesive bonding systems: Ivoclar (Group 1), 3M Unitek (Group 2), Ormco (Group 3), and Dentsply GAC (Group 4). To measure SBS, an Instron unit (Model #5943) was utilized. All debonded brackets were examined for the type of bond failure using the Adhesive Remnant Index.

Results: The mean SBS for Group 1 was 7.90±1.95 MPa, Group 2 was 7.12±1.80 MPa, Group 3 was 7.74±1.76 MPa, and Group 4 was 7.27±1.90 MPa. No statistically significant differences in SBS were found among the groups ($p = 0.912$). Although not significantly different, Group 1 had the highest SBS and the most fractured brackets at debond. There were statistically significant differences in the failure modes between Group 1 compared to Groups 2,3, and 4; with no statistically significant difference between Groups 2,3 and 4. The primary mode of bond failure for Groups 2,3, and 4 was adhesive in nature, whereas it was cohesive in nature for Group 1

Conclusions: The groups provided clinically acceptable SBS which is not high enough to cause damage to the surface of the PMMA substrate that would be evident clinically.

INTRODUCTION

The goal for an adhesive system to work in orthodontics is for it to adhere brackets to tooth surfaces for an average of roughly 28 months during orthodontics treatments (Beckwith et al., 1999).[1] Shear bond strength is an important characteristic of an adhesive system when accessing its effectiveness. Many adhesive systems currently used in orthodontics have variable shear bond strengths to different materials. The ideal shear bond strength in orthodontics was suggested to be between 5.9 and 7.8 MPa (Reynolds, 1979).[2] Adhesive systems, therefore, have been the subject of many studies which try to determine which system yields the highest shear bond strength for orthodontic applications.

Proffit et al. reported that nearly 30% of all patients seeking orthodontic treatment are adult patients (Proffit et al., 2013).[3] As a result, a search for a more esthetic bracket system which can still provide the desired results has been a focus for decades. With an increasing adult population, ceramic brackets have become more prevalent in recent years (Ramos, 2012) and have gained widespread popularity (Karamouzos, 1997).[4,5] According to Viazis, ceramic brackets debonding and pure adhesive failure require greater shear bond force compared to metal brackets (Viazis, 1990).[6] The high force used with special debonding pliers may cause failure at the adhesive-restorative material junction, resulting in damage of the restoration.

More adults seeking orthodontic treatment lead to an increasing number of cases where the orthodontist has to bond brackets to different surfaces other than enamel, including provisional restorations of computer-aided manufacturing (CAD/CAM) materials. CAD/CAM technology is used readily in many dental laboratories and private practices. A recent study by Brom-Criscola in 2013 reported that 41% of labs' total crown and bridge caseloads are CAD/CAM milled restorations and 79% of their clients are interested in CAD/CAM milled restorations.[7] This clearly proves that CAD/CAM plays an important role in modern dentistry. Therefore, more patients with existing CAD/CAM restorations, including CAD/CAM provisional crowns are expected to present for orthodontic treatment. The need to investigate bond strength between orthodontic brackets and CAD/CAM provisional restorations is inevitable. However, there are not enough studies about bond strength between ceramic brackets and provisional materials. CAD/CAM provisional blocks (including poly methyl methacrylate, PMMA blocks) used to fabricate provisional crowns are industrially-produced and have a high quality compared to chairside materials. In addition, these blocks eliminate the oxygen inhibited layer and the issues with polymerization shrinkage encountered by other chairside provisional materials (Wanner, 2010).[8] Frequently, patients, who seek orthodontic treatment as a part of a multi-disciplinary treatment plan, present with existing CAD/CAM PMMA provisional restorations. It is the orthodontist's responsibility to get familiar and have a good knowledge on what adhesive system to use in these situations.

The aim of this study was to measure the shear bond strength of 3M Clarity Advanced ceramic brackets to CAD/CAM-specific PMMA (Telio CAD, Ivoclar) blocks for provisional crowns using four different adhesive bonding systems (Ivoclar, 3M Unitek, Ormco, Dentsply GAC). The Adhesive Remnant Index was used to evaluate the site of bond failure. The null hypothesis was there would not be a significant difference in the bond strengths of ceramic brackets to the PMMA CAD/CAM blocks amongst the different adhesive bonding systems.

MATERIALS AND METHODS

A. Ivoclar Telio CAD Block Preparation

The substrates for bonding in each group were 55mm x 19mm x 15mm, industrially-fabricated PMMA CAD/CAM blocks (Ivoclar Telio CAD, size B55, Ivoclar Vivadent Inc., Amherst, NY). Each side of the blocks provided enough surface area to bond and test five brackets. The blocks have a uniformly polished surface. In order to simulate all of the steps in the process of bonding a PMMA provisional restoration to an orthodontic bracket intra-orally, the PMMA blocks were micro-abraided for 5 seconds each at a pressure of 50 PSI, from a distance of 1 inch, and at an angle of 45 degrees using 50 μm aluminum oxide powder utilizing a SandStorm Professional sand blaster (Vaniman, Fallbrook, CA). A linear, back-and-forth pattern to deliver micro-abrasion particles to the blocks was applied to ensure a uniformly abraded surface. The surfaces were then thoroughly rinsed with water and completely dried with compressed air. The blocks were then ready for the bonding procedure.

B. Experimental Groups

Four different adhesive bonding system groups were included in the experimental design. Each group consists of primer/bonding agents and adhesive resins recommended by the manufacturers. Group 1 included Ivoclar's Telio Activator, Heliobond Light-curing Bonding Resin, and Heliosit Orthodontic Resin-based Dental Luting Material for Brackets (Ivoclar Vivadent Inc., Amherst, NY). This group utilized the products and bonding technique recommended by the manufacturer of the PMMA blocks. Groups 2-4 utilized adhesive bonding systems commonly found in an orthodontic practice. Group 2 included 3M Unitek's Transbond XT Light Cure Adhesive Primer and Transbond XT Light Cure Adhesive Paste (St. Paul, MN). Group 3 was Ormco's Ortho Solo Universal Bonding Primer/Enhancer and Grengloo Two-Way Color Change Adhesive (Glendora, CA). Group 4 was Dentsply's NeoBond Primer and NeoBond Bracket Adhesive Paste (Islandia, NY).

C. Bracket Bonding Process

Eighty 3M Unitek 0.022 inch Clarity ADVANCED Ceramic brackets (tooth #8 bracket) with MBT Versatile+ prescription (Monrovia, CA) were used: twenty brackets for each group. The bracket for tooth #8 was chosen because of its relatively flat base design that interfaced well with the flat PMMA substrate surface. Manufacturer's instructions or recommended protocols were followed precisely. Each bracket was cured with Ultradent's VALO^{TM} light (South Jordan, UT) from all four sides on a five-second cycle. This light-emitting diode (LED) curing light has variable intensity output settings from 1,000 to 3,200mW/cm^2 at wavelengths between 395-480nm. A Demetron L.E.D. power meter (KaVo Kerr, Charlotte NC) was used to guarantee standardization of the light's intensity above 1,000mW/cm^2 level.

D. Test of Shear Bond Strength

The PMMA blocks with bonded brackets were mounted on an Instron-compatible jig. The Instron machine model #5943 (Norwood, MA) tested and quantified the SBS of the adhesive-coated brackets to the PMMA blocks by shearing off brackets with a single blade. The blade engaged the bracket behind the occlusal tie wings. Increasing forces was applied until bond failure occurred. The force (in Newtons) resulting in bond failure was recorded and converted to SBS expressed in megapascals (MPa). The surface area (14.53 mm^2) of the 3M Unitek ceramic bracket base enabled the force per unit area to be calculated for the samples, which then, in turn, was expressed in MPa using the 1N/mm^2=1MPa conversion equation.

E. Adhesive Remnant Index Examination

Each bracket base was examined closely under a Nikon SNZ-1B stereo microscope at 10x magnification to pinpoint the primary site of failure. The failures were described as either "adhesive in nature", where failure occurs at the interface between PMMA surface and adhesive, or "cohesive in nature", where failure occurs between the adhesive and bracket base. The Adhesive Remnant Index (ARI) was used as described in Table 1.

In assigning the ARI scores, a single blinded orthodontic resident, aside from the principal investigator, independently surveyed the brackets to prevent bias. The assessment was averaged and reported.

F. Statistical Analysis

A power analysis was conducted and it was determined that a sample size of 20 per group was adequate to detect an effect, if there was one, and reasonably reject the null hypothesis in the case it was not true. A sample size of 20 per group in four groups provided 80% power to detect an effect size of 0.9 standard deviation difference among means when testing with a single factor analysis of variance (ANOVA) at the alpha level of 0.05.

After the SBS of each sample was tested, the mean MPa and standard deviations for each group were calculated. One-way analysis of variance (ANOVA) was applied to detect significant differences in the SBS between the groups. The significance for the ANOVA was $p < 0.05$. Tukey's Post-Hoc test was then used to detect pairwise difference between the groups. The significance for this test was set at $p<0.05$.

To determine if a significant difference in ARI scores existed between the groups, a Kruskal-Wallis test was used. Then, Mann-Whitney tests were performed to determine which groups were significantly different from each other. A Bonferroni correction was used to account for the six comparisons needed to compare each group to each other. Therefore, 0.008 was set as the alpha value for the Mann-Whitney tests.

RESULTS

The SBS data for each individual bracket is displayed in Table 2 and the mean SBS and standard deviations for each group are listed in Table 3. The mean SBS values are depicted graphically in Figure 1, which shows a relatively normal distribution of data for each sample group. ARI scores were organized into mean rank with statistical difference (Table 4) and frequency distribution with the number of fractured brackets (Table 5) to show the modes of failure for each group.

DISCUSSION

All of the groups included a liquid primer/bonding agent along with a resin composite adhesive paste and required relatively similar steps in their bonding processes. The bonding groups also have some differences: Group 1 (Ivoclar), which also happened to be the manufacturer of the PMMA blocks, was different from the others in that it involved a preliminary step in the bonding process prior to application of the liquid primer. Ivoclar's recommendation was to first treat the PMMA surface with a product they call the Activator, which is a monomer that contains methyl methacrylate, ethylene glycol methacrylate, and triethylene glycol dimethacrylate. According to the documentation provided with the product, this step is designed to "activate" the surface of the restoration so that it can then be adjusted, relined, or customized. For the purposes of this study, the Activator was used on the PMMA surface in preparation for having an orthodontic bracket bonded to its surface. In addition, Group 3 (Ormco) utilized a universal primer. Universal primers typically include 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP) in their formulation. 10-MDP is designed to increase monomer penetration and resin diffusion and is considered one of the best materials available for chemical bonding (Turp et al., 2013).[9] The other three groups did not advertise themselves as universal adhesives, nor did they provide details of their chemical formulation within their included documentation, therefore it can be assumed that they do not utilize any additional functional monomers such as 10-MDP.

Group 1 had the highest average SBS at 7.90 (1.95) MPa and the most fractured brackets at debond. This may be due to the fact that this group included a preliminary step of activation of the PMMA surface. Group 2 had the lowest average SBS at 7.11 (1.80) MPa. It is important to note however, that the SBS values for all of the groups were not statistically significantly different from each other based on the one-way ANOVA ($p = 0.912$) and thus the collected data failed to reject the null hypothesis. Three of the four groups (3M, Ormco, and Dentsply GAC) had mean SBS within, while Ivoclar had mean SBS very close to being within, the acceptable range (5.9-7.8 MPa) for clinically acceptable bond strengths as determined by Reynolds (Reynolds, 1979).[2] More than likely, any of the four adhesive bonding systems tested in this study would be able to provide adequate clinical SBS in bonding a ceramic bracket to a PMMA provisional restoration that was fabricated using CAD/CAM technology.

In terms of ARI scores, the adhesive failure mode for Groups 2,3 and 4 was adhesive in nature and resulted in less than 50% of the adhesive remaining on the PMMA surface (ARI = 0 and 1). Group 1's failure mode was cohesive in nature (ARI = 2). This result points to the fact that Ivoclar's adhesive possibly formed a stronger bond to the PMMA substrate, and again possibly due to the preliminary step of activation. None of the groups caused damage to the PMMA surface that was visible to the naked eye. This finding may be helpful as a reference for orthodontists whenever any of these adhesive bonding systems is used to attach ceramic brackets to PMMA provisional crowns.

There were various weaknesses that can be identified within the design of this study and it is important to point them out. The first limitation is that some of the experimental protocols were not standardized. The temperature and humidity of the room are examples. In addition, exact amounts of the various primer and adhesive paste components were not measured. This could have caused varying degrees of polymerization during light curing, which could have subsequently affected the structural properties of the cured adhesives and their SBS values. Another variable that was not standardized during this study was the amount of force used to seat each

bracket on the PMMA surface. This could have resulted in varying thicknesses of cured adhesive between the bracket bases and substrate surfaces. According to Jain and Hama, the shear bond strength required to debond orthodontic brackets tends to increase with a decrease in the thickness of adhesive up to a point, and then decreases. And thus, brackets seated with a heavier force would result in a thinner layer of adhesive, and would have affected the force levels required to cause a bond failure (Jain et al., 2013). [10] Perhaps by ensuring tighter controls on these variables, more accurate data could have been obtained and reported.

The second limitation is the design of the Instron universal testing machine's crosshead blade that was used in this study. The crosshead blade is the portion of the machine that actually comes into contact with the bracket to apply shearing force and eventually debond the bracket. Ideally, the crosshead blade should be set to travel down along PMMA block, flush with the bonding surface to deliver the shearing force to the bracket base. However, due to a slanted tip design and its thickness, once the blade reached the bracket, it would not be flush into contact with the cured adhesive or the bracket base, but instead would contact behind the gingival tie wings of the brackets. In theory, the Instron's blade should apply a pure linear shearing force to the bracket base until bond failure and debond. Instead, the slanted surface applies a torqueing force, which this study wasn't designed to evaluate. This could have been avoided, and can be avoided in future studies, by either replacing the blade with one with a thinner tip, or by reducing the existing crosshead tip to make it thinner.

CONCLUSIONS

The adhesive groups provided clinically acceptable SBS which did not appear to be high enough to cause damage to the surface of PMMA substrate that would be evident clinically. Additional care should be considered if the Ivoclar adhesive system is to be used to attach ceramic brackets to PMMA substrate due to its high number of fractured brackets and cohesion failure in nature.

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Table 1: Adhesive Remnant Index Categories

ARI Score	Definition	Type of Failure
0	0 adhesive on PMMA surface (100% on bracket base)	Adhesive Failure
1	<50% adhesive on PMMA surface (>50% on bracket base)	Adhesive Failure
2	>50% adhesive on PMMA surface (<50% on bracket base)	Cohesive
3	100% adhesive on PMMA surface with clear imprint of bracket base (0 adhesive on bracket base)	Cohesive

Table 2: SBS Values Recorded at Bond Failure

	Group 1: IVOCLAR		Group 2: 3M UNITEK		Group 3: ORMCO		Group 4: DENTSPLY GAC	
#	N	MPa	N	MPa	N	MPa	N	MPa
1	91.25	6.28	131.5	9.05	122.07	8.40	86.62	5.96
2	129.36	8.90	153	10.53	85.58	5.89	95.41	6.57
3	84.8	5.84	149.85	10.31	146.83	10.11	141.96	9.77
4	109.5	7.54	68.82	4.74	70.83	4.87	85.61	5.89
5	104.87	7.22	113.7	7.83	104.37	7.18	120.93	8.32
6	170.72	11.75	81.06	5.58	111.99	7.71	75.23	5.18
7	98.17	6.76	67.86	4.67	90.78	6.25	144.27	9.93
8	143.66	9.89	95.44	6.57	81.63	5.62	70.34	4.84
9	178.34	12.27	81.82	5.63	124.83	8.59	121.88	8.39
10	138.53	9.53	91.49	6.30	112.36	7.73	138.7	9.55
11	123.39	8.49	60.29	4.15	92.57	6.37	132.29	9.10
12	91.9	6.32	85.8	5.91	140.53	9.67	107.4	7.39

13	73.57	5.06	95.25	6.56	105.82	7.28	114.36	7.87
14	121.44	8.36	112.11	7.72	153.55	10.57	64.38	4.43
15	94.13	6.48	92.81	6.39	114.63	7.89	68.43	4.71
16	104.36	7.18	133.53	9.19	138.78	9.55	93	6.40
17	94.93	6.53	107.77	7.42	101.47	6.98	109.04	7.50
18	115.44	7.94	119.26	8.21	87.22	6.00	77.31	5.32
19	87.02	5.99	107.63	7.41	163.38	11.24	151.74	10.44
20	140.21	9.65	119.42	8.22	100.7	6.93	115.27	7.93

Table 3: SBS by Mean, Standard Deviation, and Statistical Difference

Group #	MPa (Standard Deviation)*
1	7.90 (1.95) a
2	7.12 (1.80) a
3	7.74 (1.76) a
4	7.28 (1.90) a
**Groups with the same lower case letter are not significantly different (p>0.05)*	

Figure 1: Shear Bond Strength Box Plot

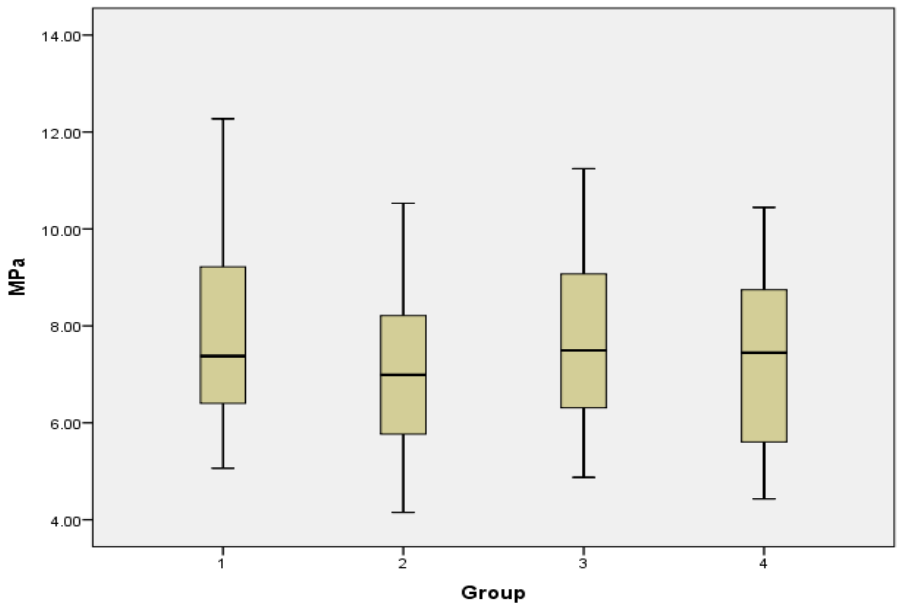

Table 4: ARI Scores by Mean Rank and Statistical Difference

Group #	Mean Rank *
1	54.83 a
2	26.53 b
3	32.19 b
4	23.75 b
**Groups with the same lower case letter are not significantly different (p>0.05)*	

Table 5: ARI Scores by Frequency Distribution of Failure Modes

	ARI Scores				
Group #	**0**	**1**	**2**	**3**	**Fractured**
1	0	1	5	0	14
2	11	6	0	0	3
3	7	9	0	0	4
4	15	5	0	0	0