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Shear Bond Strength of a New Flowable Composite to a Ceramic CAD/CAM Material

A Thesis

Presented to the Faculty of the Advanced Education in General Dentistry, Two-Year Program,

United States Army Dental Activity, Fort Hood, Texas

And the Uniformed Services University of the Health Sciences – Post Graduate Dental College

In Partial Fulfillment of the Requirements for the Degree of

Master of Science in Oral Biology

By

Marlowe Anthony S. Rillera, CPT USA DC

April 2017

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Shear Bond Strength of a New Flowable Composite to a Ceramic CAD/CAM Material

A REPORT ON

Research project investigating the shear bond strength of three resin composite materials (NovaPro Flow, Filtek Supreme Ultra Flowable, and Henry Schein Natural Elegance Flowable Composite) to a CAD/CAM ceramic material (Ivoclar IPS Empress CAD). .

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ABSTRACT

Purpose: The purpose of this study is to analyze the shear bond strength of three resin composite materials (NovaPro Flow, Filtek Supreme Ultra Flowable, and Henry Schein Natural Elegance Flowable Composite) to a CAD/CAM ceramic material (Ivoclar IPS Empress CAD). The comparisons will be analyzed to determine if any of the composites is a more preferable choice in repairing anterior indirect restorations made from IPS Empress CAD.

Methods: 99 samples were prepared for testing and divided into three groups. Group 1: NovaPro Flow bonded to Empress, Group 2: Filtek Supreme Ultra Flowable bonded to Empress, and Group 3: Henry Schein Natural Elegance Flowable Composite bonded to Empress. The surface of the IPS Empress CAD was polished, etched with 9.6% hydrofluoric acid etch, and treated with silane. The bonded composite samples were sheared off in a universal testing machine (MTS). Lastly, the samples were examined under a microscope to analyze method of failure (adhesive, cohesive, mixed).

Results: A total of 99 samples were included in this study (33 per group). The mean shear bond strength of Group 1 was 7.277 MPa with a standard deviation of 4.284. The mean shear bond strength of Group 2 was 7.212 MPa with a standard deviation of 2.506. The mean shear bond strength of Group 3 was 8.368 MPa with a standard deviation of 3.740. According to the one-way ANOVA and Tukey Kramer HSD tests, there was no statistical significance in shear bond strength between groups ($p>.05$). In general, each group exhibited adhesive bond failures at the bonding interface. Group 3 exhibited five cohesive failures, while the other two groups only produced one cohesive failure each.

Conclusion: NovaPro Flow utilizes novel technology in its chemical composition, being marketed as the industry's first nanofiber-reinforced nanohybrid composite. The manufacturer, Nanova Biopharmaceuticals Inc., claims superior bond strength and other more desirable mechanical properties when compared to other nanocomposites. However, in this study, we did not find NovaPro Flow to have a statistically significant increase in shear bond strength to IPS Empress CAD when compared to two nanohybrid composites: Filtek Supreme Ultra Flowable and Henry Schein Natural Elegance. Natural Elegance Flowable had the highest mean shear bond strength of the three, but the results were not statistically significant. Thus, based on our study, clinicians can expect to receive comparable results when using either a nanohybrid or nanofiber-reinforced nanohybrid composite during repair of anterior indirect restorations. However, clinicians must still use sound clinical judgment to determine when repair of a ceramic restoration is indicated over replacement of the entire prosthesis.

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DISCLAIMER

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INTRODUCTION

The use of Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) in dentistry has grown tremendously in recent years. Same-day delivery of crowns, decreased need for provisionals, enhanced esthetics, digital impression-taking, and increased efficiency are just some of the reasons why dentistry is embracing CAD/CAM technology.[1,2] The applications for CAD/CAM technology in dentistry include inlays, onlays, single unit crowns, fixed partial dentures, and implant abutments/prostheses. Not only is CAD/CAM being used more in the clinical/chairside setting, but dental laboratories are increasingly switching to a digital workflow. There are now laboratories that can utilize CAD/CAM technology in the fabrication of complete and partial dentures.[3]

With regards to fixed prosthodontics, there have been numerous studies that have elucidated the effectiveness and longevity of CAD/CAM restorations. In 2009, Wittneben et al. conducted a systematic review on the clinical performance of single unit monolithic CAD/CAM restorations. They found the estimated 5 year survival rate of such restorations to be 91.6%, with a mean failure rate of only 1.75% per year over a 7.9 year period.[4] Another long term study conducted by Zimmer et al. gave similar results, finding a survival rate of 94.7% over a five year period and 85.7% after a ten year period.[5] The longevity of CAD/CAM ceramics can be attributed to the strength of the ceramic material as well as the excellent marginal adaptation derived from these prostheses. When compared to metal ceramic crowns, monolithic ceramic crowns have been found to produce similar marginal discrepancies that are well within the range of clinical acceptance.[6,7] With this developing track record for clinical success, dentists are increasingly shifting their material of choice from porcelain fused to metal (PFM) to more esthetic all ceramic CAD/CAM materials.[8]

Thus, as CAD/CAM restorations become more prevalent, it is necessary for dentists to practice methods to repair and replace these restorations. There are several etiologies for failure of an all ceramic restoration. These may include secondary caries, cracks, fractures, irreversible pulpitis, parafunction, inadequate material thickness, and excessive wear of the opposing dentition.[9] Oftentimes, ceramic defects and failures are caused by a combination of the aforementioned factors. Given the dynamic nature of occlusion and individual patient variation, it has proven difficult to establish a standard *in vitro* testing protocol that can accurately reproduce the fractures and failures seen *in vivo*.[10,11] The propagation of a crack throughout a ceramic is a function of both the magnitude and direction of the forces being applied. Regardless of how the ceramic may fracture, dentists should be aware of the mechanical properties of dental ceramics. They are more brittle than metals, and therefore are more prone to chips, cracks, and fractures.[12] These events are usually of high importance to the patient because esthetics and tooth restorability can be compromised.

The literature shows several different methods of repairing a fractured ceramic restoration. The treatment rendered should be case-by-case, with the dentist taking into consideration the size of the fracture, the location of the fracture, the type of material, and the associated occlusal forces at the site. The main repair methods include re-bonding of the fractured portion, repair of the fracture with resin composite, or replacement with an entirely new restoration. This study aims to investigate composite repair.

When ceramic CAD/CAM crowns fracture, the defect may be small enough to consider repairing the restoration instead of replacing it entirely. Several research and case studies have shown that resin composite is a successful repair material for ceramic.[13-16] The literature also shows that, prior to bonding, surface treatment of the ceramic plays a significant role. Treatments that create more surface roughness in the ceramic result in higher bonding strengths of the composite repair. Possible surface treatments include aluminum oxide abrasion, laser irradiation, hydrofluoric acid etching, silanation, and mechanical abrasion with a diamond bur. Hydrofluoric acid etching with silanation has been found to be the most effective combination across numerous studies,[17-20] which is why this surface treatment was chosen for this study. Hydrofluoric acid has been shown to produce the highest levels of surface roughness to feldspathic, leucite-reinforced, and lithium disilicate ceramics.[21] However, hydrofluoric acid etching is not indicated in zirconia prostheses, as the treatment does not alter the surface topography of this material.[22]

When deciding which composite to repair a defect with, the clinician is faced with a vast multitude of options. Recently in October 2015, Nanova Biomaterials Inc. received FDA approval to begin selling its new product, NovaPro Flow. This new flowable composite is being advertised as the industry's first nanofiber-reinforced nanohybrid composite.[23] In addition to the barium borosilicate filler particles, the composite is also infused with hydroxyapatite nanofibers (Figure 1). The hydroxyapatite nanofibers have a diameter of less than 100 nanometers, and comprise 1-10% of the material. The full chemical composition of NovaPro Flow is presented in Figure 2. According to the manufacturer, the nanofiber and nanoparticle combination increases the strength and longevity of the material beyond that of the commonly used nanohybrid composites. This is due to the nanofibers being able to resist shear, tensile, and bending forces better than nanoparticles. The manufacturer utilizes the analogy of rebar-reinforced concrete compared to concrete alone. Based on the manufacturer's brochure, one of the FDA-cleared uses for NovaPro Flow is direct and indirect restoration repair. Thus, this study aims to determine if this new material's unique properties make it a more preferable choice for repairing CAD/CAM ceramic restorations when compared to two nanohybrid composites.

This study has a great deal of significance with regards to Army dentistry. The US Army is embracing technological advances in CAD/CAM dentistry, with a majority of dental clinics being outfitted with digital scanners and milling units. The number of CAD/CAM restorations in military patients is growing dramatically and thus, military dentists must be knowledgeable about all aspects of the materials. Military dentists should know the techniques and materials needed to repair these prostheses. Resin composite is readily available in all dental clinics, so even a deployed dentist overseas should be able to perform ceramic repairs. If a dentist is able to recognize which crowns can simply be repaired, this would save the Army considerable time and money because an entirely new crown would not have to be designed and milled. Less time spent with that patient means more time the practitioner can devote to another soldier in need. Ivoclar IPS Empress CAD is one of the more commonly used CAD/CAM materials in the Army. It is a leucite-reinforced glass/ceramic block, and is generally used to restore premolars and anterior teeth. If the new composite, NovaPro Flow, exhibits superior bond strengths to Empress in our study, then this could be an indication to start purchasing this new material for military dental clinics.

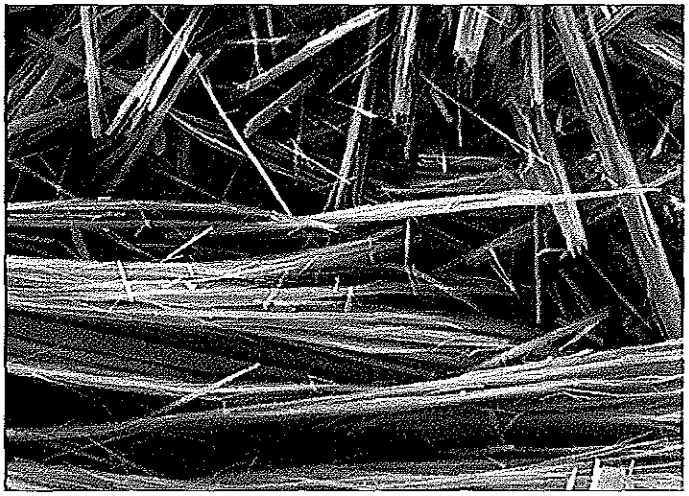


Figure 1: SEM of hydroxyapatite nanofibers, adapted from NovaPro Flow brochure

Chemical Name	C.A.S. No.	Percent
Hydrophobic Amorphous Fumed Silica	68611-44-9	1-10
Barium Borosilicate Glass	65997-17-3	40-80
Ethoxylated Bis Phenol A Dimethacrylate	41637-38-1	5-25
Triethylene Glycol Dimethacrylate	109-16-0	1-10
Urethane Dimethacrylate	72869-86-4	5-25
Hydroxyapatite	7758-87-4	1-10

Figure 2: Chemical composition of NovaPro Flow, based on MSDS

PURPOSE

The purpose of this study is to analyze the shear bond strength of three resin composite materials (NovaPro Flow, Filtek Supreme Ultra Flowable, and Henry Schein Natural Elegance Flowable Composite) to a CAD/CAM ceramic material (Ivoclar IPS Empress CAD). The comparisons will be analyzed to determine if either a nanohybrid or nanofiber-reinforced nanohybrid is more indicated during repair of anterior indirect restorations made from IPS Empress CAD.

HYPOTHESES

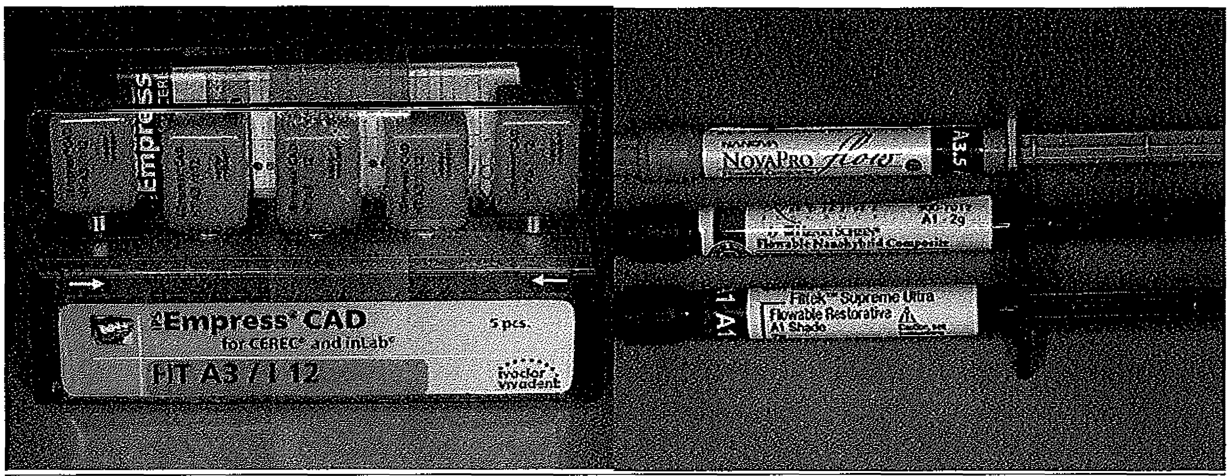
Research questions: Will there be a significant difference in shear bond strength of NovaPro Flow to IPS Empress CAD when compared to two other composites? Will there be any significant differences in failure mode between the three composites?

Null hypothesis #1: There will be no significant difference in shear bond strength of NovaPro Flow, Filtek Supreme Ultra Flowable, and Henry Schein Natural Elegance Flowable Composite to IPS Empress CAD.

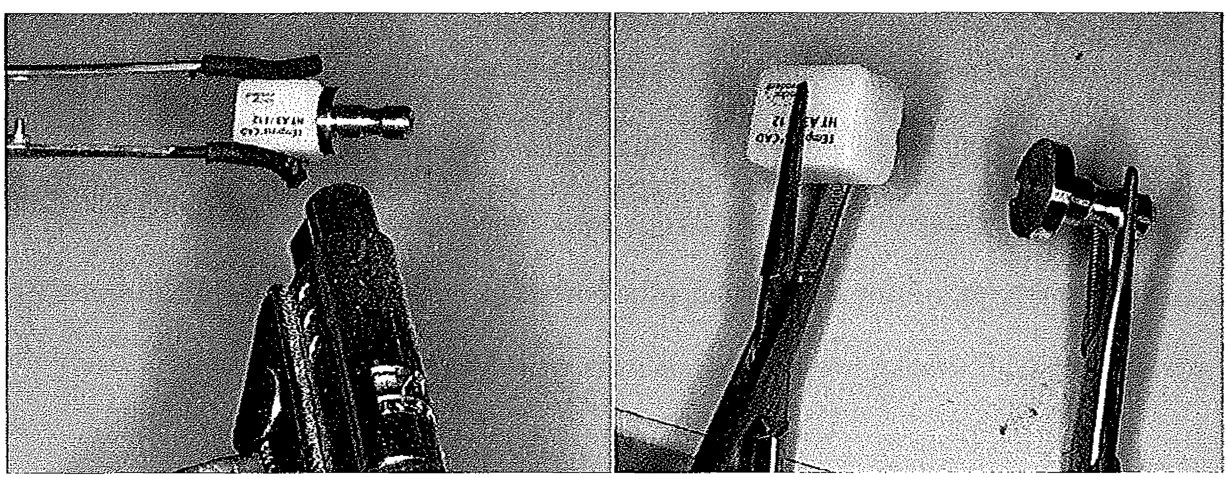
Null hypothesis #2: There will be no significant relationship between bond strength and failure mode of the composites bonded on to IPS Empress CAD.

MATERIALS AND METHODS

A total of 33 IPS Empress CAD blocks (Ivoclar Vivadent, Liechtenstein, Germany) and 4 tubes of each flowable composite were used in this study (Picture 1a and 1b). Prior to surface preparation, the metal stems were removed from the IPS Empress CAD blocks. The stems were heated with a micro-torch to melt the adhesive (Picture 2a) to allow for manual removal of the stem with hemostats (Figure 2b).



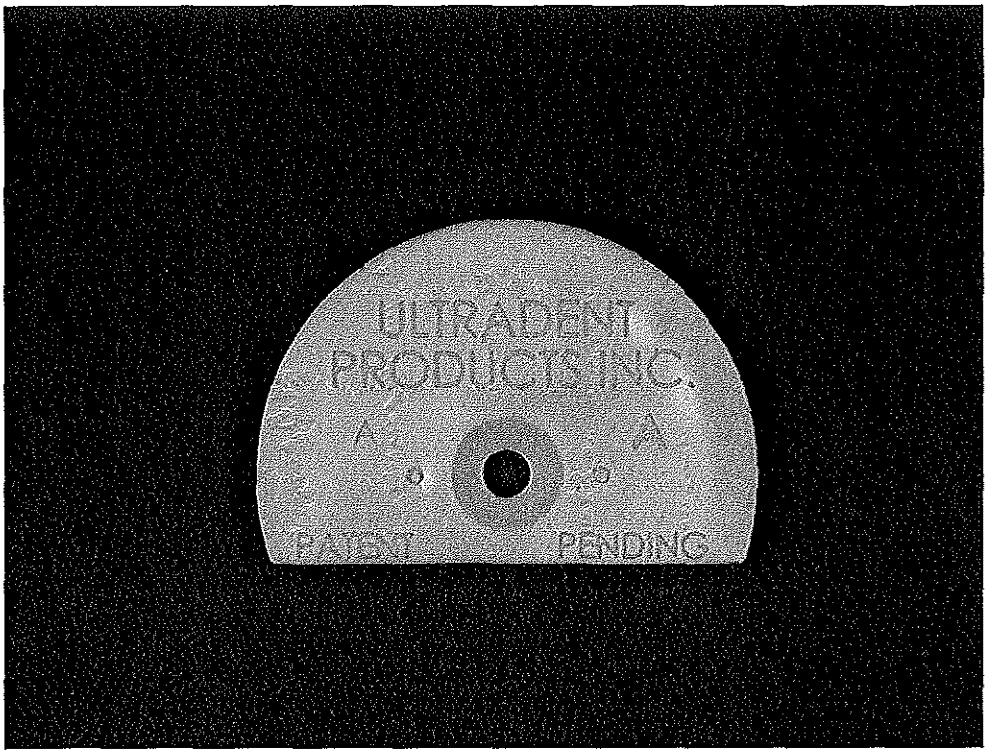
Picture 1a, 1b: IPS Empress CAD (a) and flowable composites that were tested (b): NovaPro Flow, Filtek Supreme Ultra Flowable, and Henry Schein Natural Elegance.



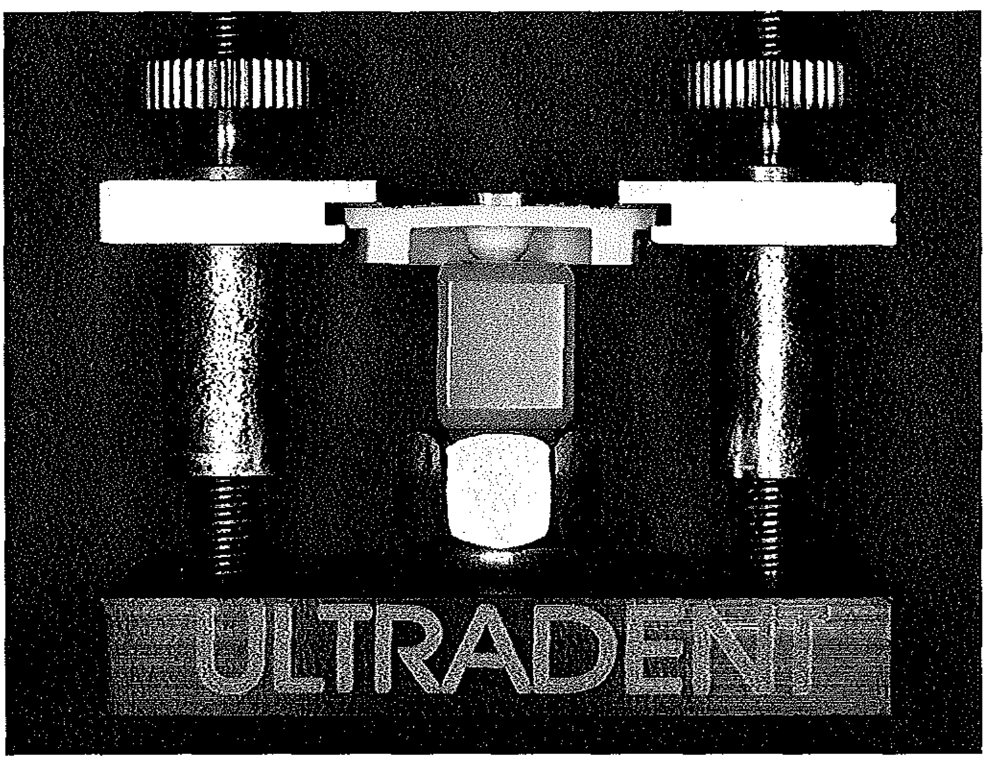
Picture 2a, 2b: Heating (a) and separating (b) the block of Empress ceramic from the metal stem.

Three sides of each Empress block served as bonding surfaces (99 total surfaces). All bonding surfaces underwent a standard surface preparation as described: Surfaces were cleaned with coarse laboratory pumice (Henry Schein, Melville, NY) and a rag wheel at 3000 rpm for approximately 5 seconds. Specimens were rinsed thoroughly with water and air dried to assure no pumice remained on the bonding surface. On each block, the corner of each bonding surface was labeled 1, 2, or 3, corresponding to the following groups: Group 1 - NovaPro Flow, Group 2 - Filtek Supreme Ultra Flowable, and Group 3 - Henry Schein Natural Elegance Flowable.

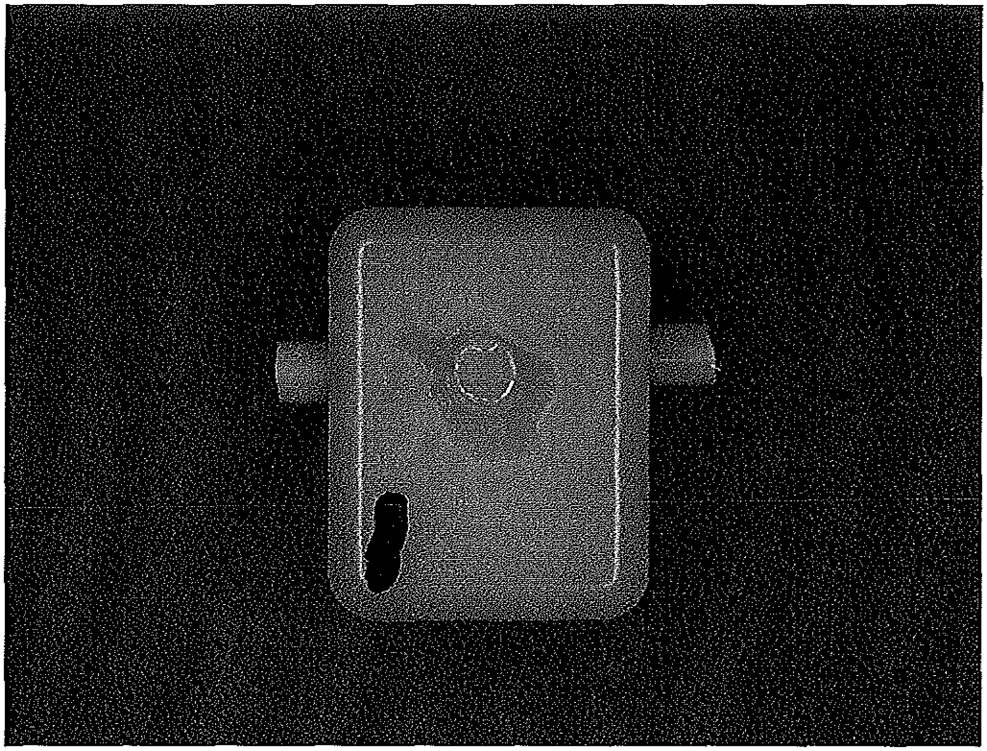
Each ceramic bonding surface was then treated as follows: 1) 9.6% hydrofluoric acid porcelain etch (Pulpdent, Watertown, MA) for 60 seconds and then rinsed with water. 2) Silane coupling agent (Pulpdent, Watertown, MA) applied with brush and air dried for 1 minute. 3) Optibond SoloPlus (Kerr Dental, Orange, CA) applied and cured for 20 seconds per manufacturer's instruction with an LED curing light, Demi Plus (Kerr Dental, Orange, CA). Each individual sample was prepared separately to assure standardized timing for each step. Composite buttons, approximately 2.38 mm in diameter, were applied to specimen surfaces in accordance with ISO 29022[25], the notched edge shear bond strength test. The jig used to form the buttons included a standardized button mould (Picture 3), bonding clamp mechanism (Picture 4), and metal washer (Ultradent Products Inc., South Jordan, UT). The metal washer was used to allow space for the composite button on the opposite surface of the Empress block. Care was taken to not hit the previously formed composite buttons onto the metal washer. A finished Empress block with samples from each group is shown (Picture 5).



Picture 3: Button mould, Ultradent Products, Inc.



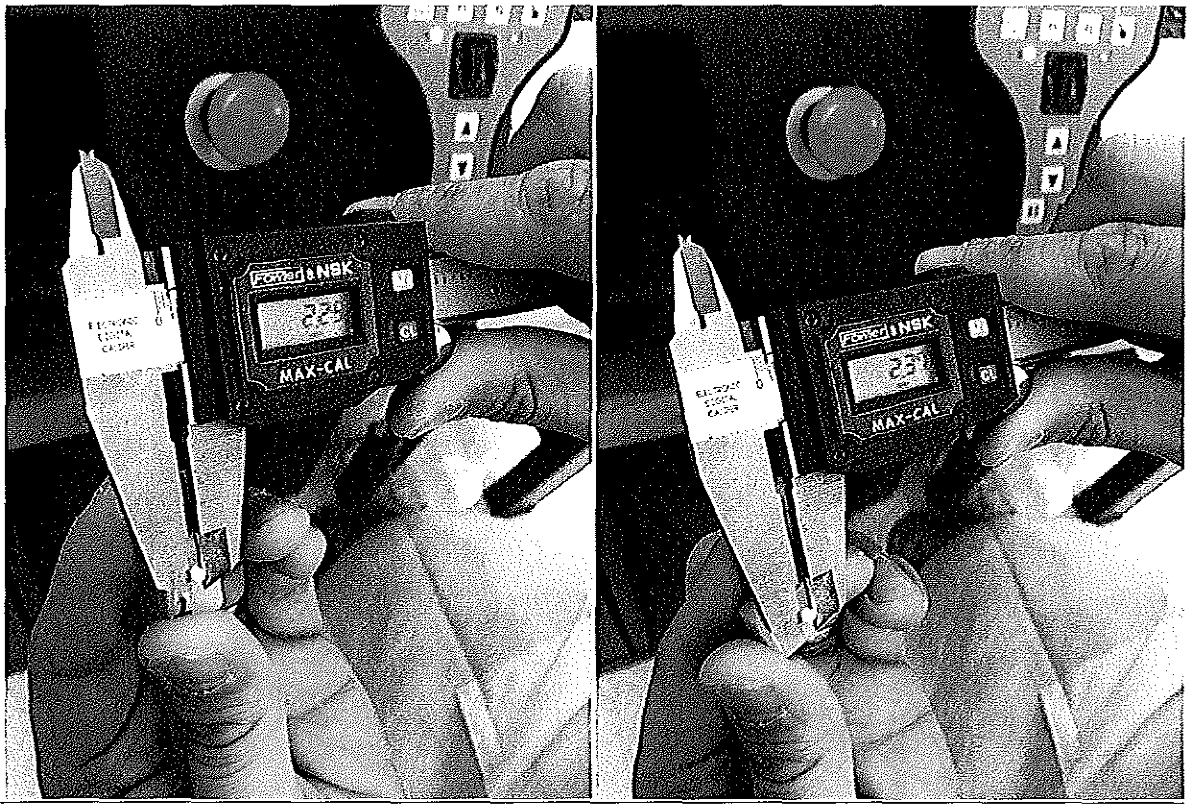
Picture 4: Ultradent jig used for creating composite samples on each block.



Picture 5: Empress block with three samples bonded (one sample from each group).

After sample preparation was complete, the Empress blocks were individually wrapped with bubble wrap and securely packaged. Sample preparation was completed at Fort Hood, TX, and the bond strength testing was completed at the USAF Dental Evaluations and Consultation Service (DECS). Two separate visits to DECS were made, with half of the samples tested at each visit.

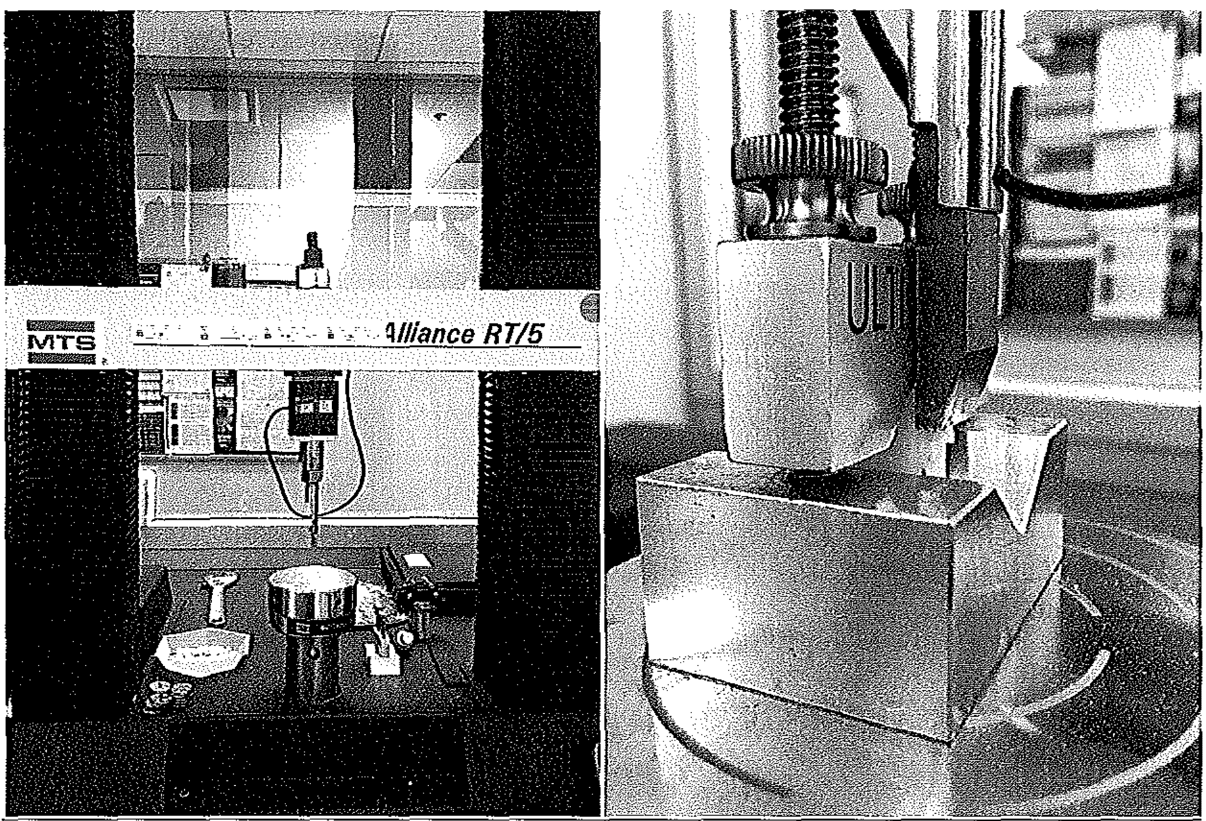
Prior to shear bond strength testing, the diameter of each sample was measured with digital calipers at two different arbitrary sites (Picture 6a, 6b). The average of these two measurements was calculated and used as the "measured diameter". This value was used for calculation of the bond strength in megapascals (MPa), a unit that is measured in force per unit area. Even though the diameter of the standardized button former is 2.38 mm, the composite did not flow into the button former uniformly for each sample. Thus, diameter measurements needed to be taken for more accurate results.



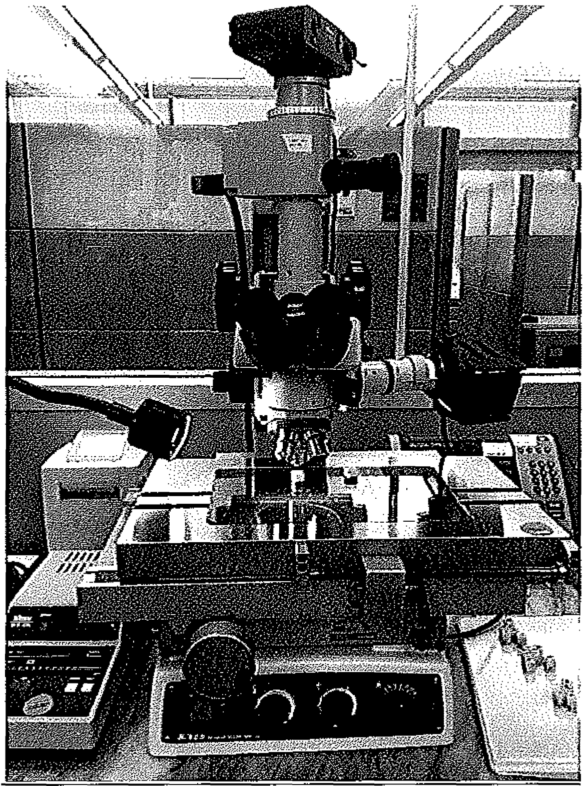
Picture 6a, 6b: The diameter of each sample was measured at two different spots. The average of these two values was the diameter used to calculate the area of each sample.

Each specimen was then secured into an Ultradent test base clamp (Picture 7) and loaded into an MTS universal testing machine (Picture 8a). The long axis of the specimen was perpendicular to the applied force of the crosshead assembly. Bond strength was determined in shear mode at a crosshead speed of 1.0 mm/minute until the MTS detected a fracture (Picture 8b). Lastly, samples were analyzed microscopically to determine failure mode (Picture 9). Failures were classified as adhesive (A), cohesive (C), or mixed (M) failures. Mixed failures were assigned when the sample showed approximately 50% adhesive and 50% cohesive failure.

Picture 7: Test sample loaded into Ultradent jig.



Picture 8a, 8b: MTS universal testing machine (a) and crosshead assembly shearing off a sample (b).



Picture 9: Nikon Measurescope MM-22 used to analyze method of failure.

In this study, the independent variable is composite (Na). The dependent variable is shear bond strength measured with the MTS in megapascals (N/mm^2). The null hypothesis is that there is no difference in shear bond strength with respect to composite. The alternative hypothesis is that there is a difference in shear bond strength with respect to composite. The appropriate test is a one-way ANOVA followed by post hoc independent sample t-tests corrected for multiple comparisons. If the data are not normally distributed with equal variance, the equivalent non-parametric test will be used. A two-way ANOVA will be used to compare mean shear bond strength and failure mode.

A mean standard deviation (SD) for the dependent variable was not estimated, so a general analysis was performed. Three comparisons are appropriate for this design so we used a

Bonferroni correction of $p = 0.05/3 = 0.017$. We used the on line power analysis program at the University of British Columbia (www.stat.ubc.ca/~rollin/stats/ssize/n2.html) to estimate the sample size needed for a power of 80% with a level of confidence of 95%. Effect size is the difference in group means measured in standard deviations (SD). With 33 samples per group, we were able to detect an effective size of 0.8 SD.

RESULTS

A total of 99 samples were included in this study, divided into three groups: Group 1 – NovaPro Flow bonded to Empress, Group 2 – Filtek Supreme Ultra Flowable bonded to Empress, and Group 3 – Henry Schein Natural Elegance Flowable bonded to Empress. The mean shear bond strength of Group 1 (Em+Nova) was 7.277 MPa with a standard deviation of 4.284. The mean shear bond strength of Group 2 (Em+Filtek) was 7.212 MPa with a standard deviation of 2.506. The mean shear bond strength of Group 3 (Em+HS) was 8.368 MPa with a standard deviation of 3.740 (Figures 1 and 2). According to the one-way ANOVA, there was no statistically significant difference ($p>.05$) found in shear bond strength between the three groups (Figure 2). Further analysis of the means was completed through the Tukey-Kramer honest significant difference (HSD) test. This post hoc test again resulted in no significant difference ($p>.05$) in shear bond strength between the means of the three groups (Figure 3a and 3b).

Interestingly, for all three groups, shear bond strengths were lower during the second visit (Figure 4). For NovaPro Flow, the mean shear bond strength was 9.590 MPa for the first visit and 4.820 MPa for the second visit. For Filtek Supreme Ultra Flowable, the mean shear bond strength was 8.697 MPA for the first visit and 5.634 for the second visit. For Henry Schein Natural Elegance Flowable, the mean shear bond strength was 10.400 MPa for the first visit and 6.209 MPa for the second visit. A two-tailed T-test was performed for each flowable composite, comparing the mean shear bond strengths of each visit. For all three groups, the T-test found a significant difference ($p<.05$) in mean shear bond strengths between visits (Figures 5, 6, and 7).

Each group exhibited mostly adhesive failures of the samples (Figure 8). Filtek Supreme Ultra Flowable exhibited the most mixed failures (eight samples) while Henry Schein Natural

Elegance Flowable exhibited the most cohesive failures (five samples). For Henry Schein Natural Elegance and Filtek Supreme, the failure mode that yielded the highest average bond strength was the cohesive failure. On the other hand, cohesive failures yielded the lowest mean bond strength out of all the failure types for NovaPro Flow (Figure 9). A two-way ANOVA was run to compare mean shear bond strengths and mode of failure. There was no statistical significance ($p>.05$) found between bond strength and failure mode for the three groups (Figure 10).

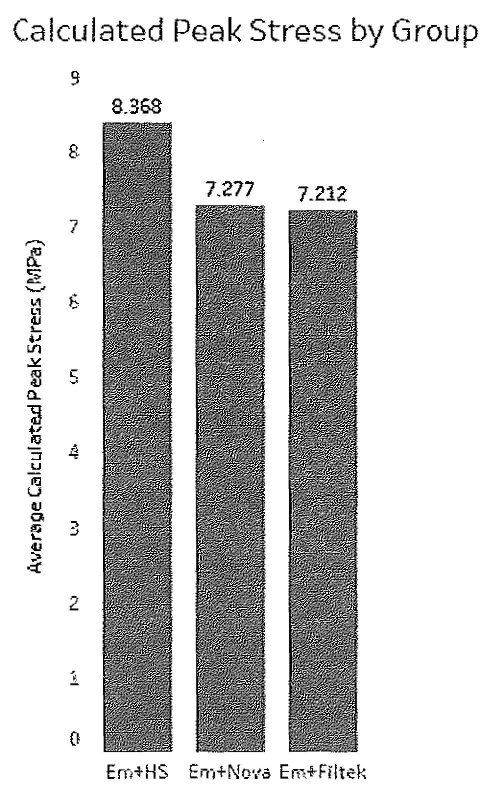


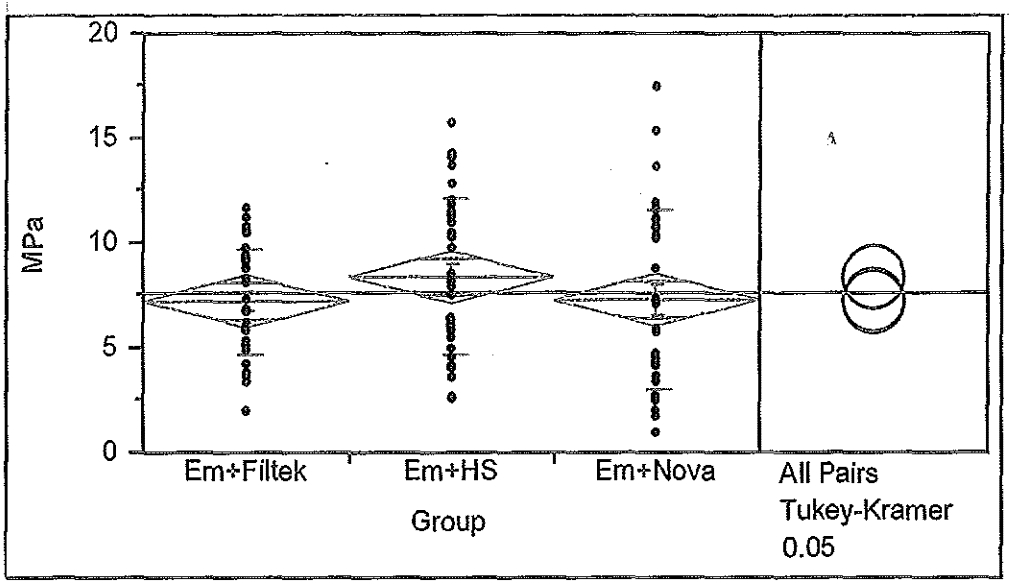
Figure 1: Calculated Peak Stress by group, measured in MPa

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Em+Filtek	33	7.21180	2.50610	0.43626	6.3232	8.1004
Em+HS	33	8.36815	3.73974	0.65100	7.0421	9.6942
Em+Nova	33	7.27698	4.28442	0.74582	5.7578	8.7962

Figure 2: Means and standard deviations

Oneway Analysis of MPa By Group



Oneway Anova

Summary of Fit

Rsquare	0.022039
Adj Rsquare	0.001665
Root Mean Square Error	3.588056
Mean of Response	7.618976
Observations (or Sum Wgts)	99

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Group	2	27.8522	13.9261	1.0817	0.3431
Error	96	1235.9178	12.8741		
C. Total	98	1263.7700			

Comparisons for all pairs using Tukey-Kramer HSD

LSD Threshold Matrix

Abs(Dif)-HSD

	Em+HS	Em+Nova	Em+Filtek
Em+HS	-2.1029	-1.0117	-0.9465
Em+Nova	-1.0117	-2.1029	-2.0377
Em+Filtek	-0.9465	-2.0377	-2.1029

Positive values show pairs of means that are significantly different.

Connecting Letters Report

Level		Mean
Em+HS	A	8.3681457
Em+Nova	A	7.2769794
Em+Filtek	A	7.2118028

Levels not connected by same letter are significantly different.

Figure 3a and 3b: Results of Tukey-Kramer HSD test, showing no statistically significant difference in the means of the three groups.

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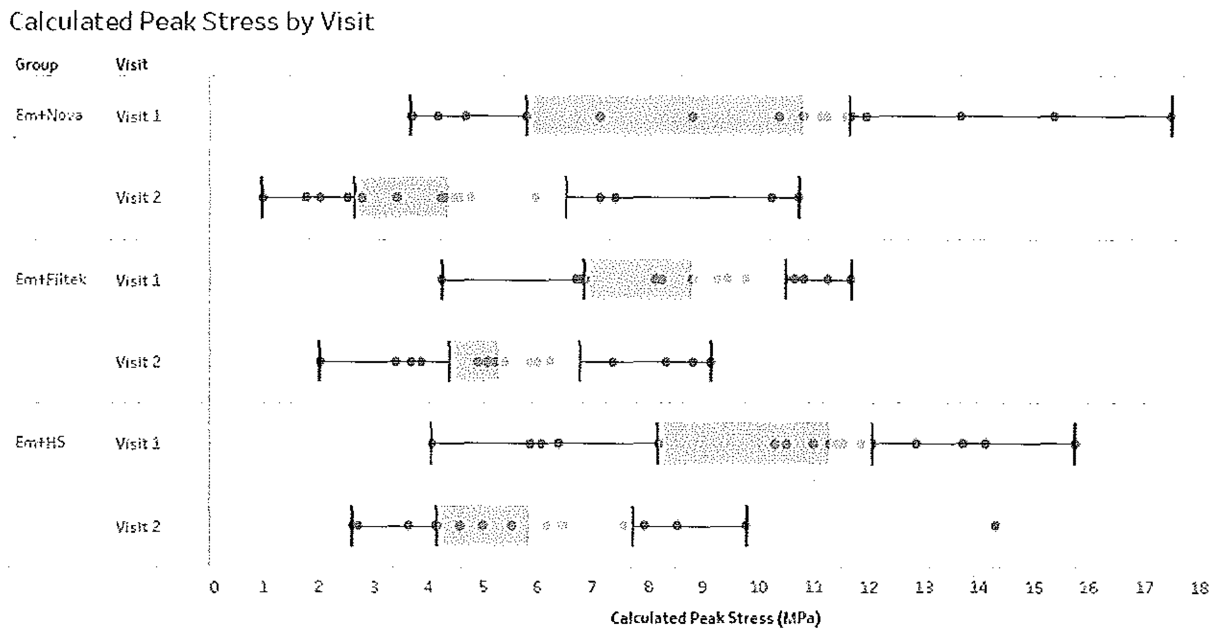

Figure 4: Calculated Peak Stress (MPa) for the three groups, separated by visit

	Group 1		Group 2
Mean	9.5896		4.8198
Variance	17.3892		8.1098
Stand. Dev.	4.17		2.8478
n	17		16
t		**3.8129**	
degrees of freedom		**31**	
critical value		**2.04**	

Figure 5: T-test results for NovaPro Flow bond strengths from visit 1 and visit 2, labeled Group 1 and Group 2 respectively. The calculated t-value exceeds the critical value, so the means are statistically significant with p=.000613.

	Group 1		Group 2
Mean	8.697		5.6338
Variance	4.0063		3.9691
Stand. Dev.	2.0016		1.9923
n	17		16
t		**4.4035**	
degrees of freedom		**31**	
critical value		**2.04**	

Figure 6: T-test results for Filtek Supreme Ultra bond strengths from visit 1 and visit 2, labeled Group 1 and Group 2 respectively. The calculated t-value exceeds the critical value, so the means are statistically significant with p=.000118.

	Group 1		Group 2
Mean	10.4001		6.2092
Variance	10.5627		8.9182
Stand. Dev.	3.25		2.9863
n	17		16
t		**3.8499**	
degrees of freedom		**31**	
critical value		**2.04**	

Figure 7: T-test results for Henry Schein Natural Elegance bond strengths from visit 1 and visit 2, labeled Group 1 and Group 2 respectively. The calculated t-value exceeds the critical value, so the means are statistically significant with p=.000277.

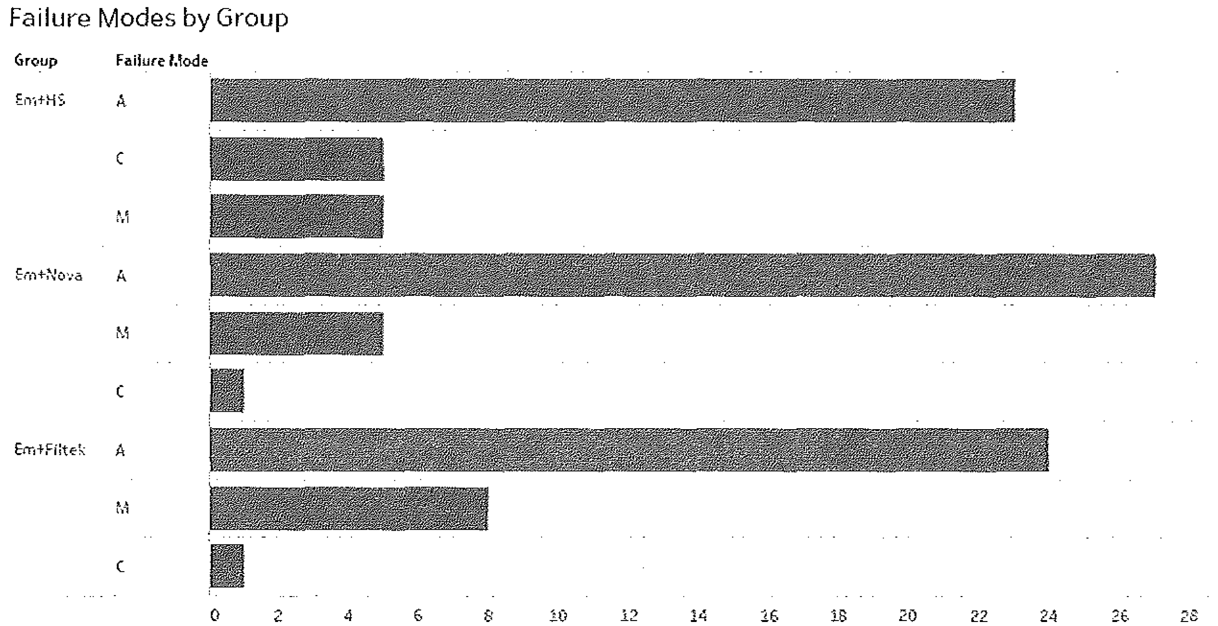

Figure 8: Failure modes by group. A – adhesive failure, C – cohesive failure, M – mixed failure

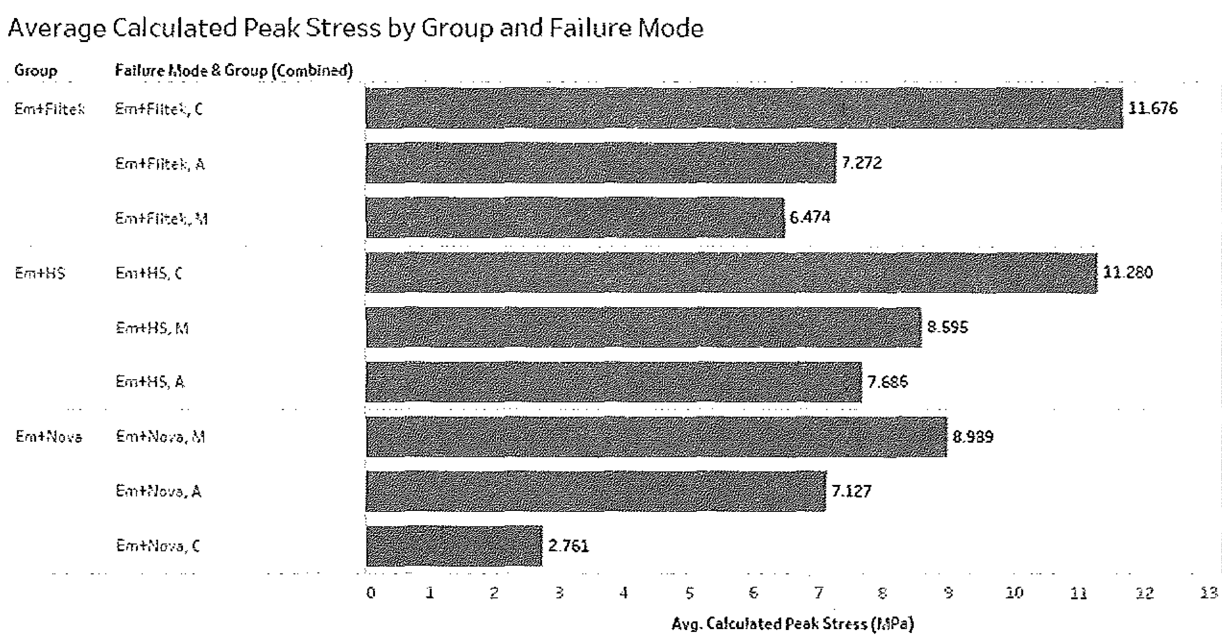

Figure 9: Average calculated peak stress (MPa) separated by group and failure mode

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Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	8	141.2505	17.6563	1.4156
Error	90	1122.5195	12.4724	**Prob > F**
C. Total	98	1263.7700		0.2008

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Group	2	2	44.889048	1.7995	0.1713
FxMode	2	2	10.638433	0.4265	0.6541
Group*FxMode	4	4	76.405046	1.5315	0.1998

Figure 10: Two-way ANOVA analyzing relationship between bond strength and failure mode. F>.05, which shows no statistical significance between bond strength and failure mode.

DISCUSSION

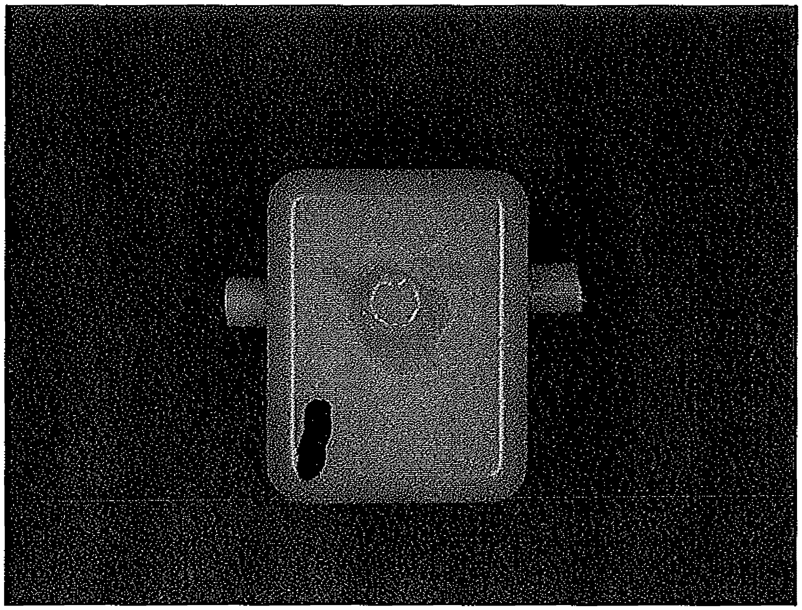
NovaPro Flow is a new flowable composite that has recently come to market. It uses novel technology and is being advertised as the first nanofiber-reinforced nanohybrid composite. The manufacturer claims that the product's hydroxyapatite nanofibers increase bond strength as well as resistance to shear and tensile forces. One of the FDA-cleared uses for NovaPro Flow is repair of anterior indirect ceramic restorations. There are currently no studies in the literature that compare this new product to other composites when bonded to CAD/CAM ceramic materials.

In this study, all composite samples were bonded on to IPS Empress CAD. The Empress surfaces were treated with only one means of surface preparation: hydrofluoric acid etching and silanation. The mean shear bond strengths of NovaPro Flow, Filtek Supreme Ultra Flowable, and Henry Schein Natural Elegance were 7.277 MPa, 7.212 MPa, and 8.368 MPa, respectively. These values approximate bond strength values found across similar shear bond studies in the literature. In 2014, a study by Erdemir analyzed the shear bond strength of Vertise Flowable composite to IPS e.max CAD.[26] The investigators recorded bond strength measurements under various surface preparations of the ceramic. The samples prepared with hydrofluoric acid etching and silanation produced a mean shear bond strength 6.82 MPa. In another study investigating resin composite cements, Bahr found mean shear bond strength values in the range of 2.8 MPa to 19.6 MPa.[27]

Wide variation in bond strengths is not uncommon in shear bond studies due to the nature of resin adhesive. Adhesive dentistry is very technique sensitive, with the possibility of introducing error at any step of the process. In our study, we recorded bond strength values ranging from 0.973 MPa to 17.484 MPa. This bench-top study attempted to reduce error by standardizing methods and materials for the preparation of each sample. However, statistically significant bond strength values were still seen across both visits. This shows that error was still introduced in this study despite adherence to strict controls.

The introduction of human error could have first been seen in the sample preparation process. The IPS Empress CAD blocks were each polished for 5 seconds with coarse laboratory pumice. Although the timing may have been equilibrated for each sample, the pressure applied onto the rag wheel may have differed slightly across samples. This would have resulted in varying degrees of surface smoothness of the ceramic substrate prior to hydrofluoric acid etching.

Another section where error could have been introduced was in the bonding process itself. Optibond SoloPlus was applied with a microbrush and air dried per manufacturer's instructions. Application of the bonding agent could not be standardized due to the fact that each application produced different thickness measurements of the bonding agent. This thickness is all dependent on how much bonding agent the investigator procured each time with the microbrush, and this could have varied from one sample to the next. Another possible source of variability could have been in the creation of the composite buttons. The customized button formers attempt to standardize the diameter of each same, but it was especially difficult to fill the button formers to the exact same level with the flowable composite. The depth of the button former is approximately 3 mm, and varying heights of the samples are seen in the picture below (Picture 1). This could have affected the bond strength because samples with greater depth may have achieved less polymerization of the composite at the bonding interface, which is the deepest part of the composite sample.



Picture 1: Note the difference in depth of the samples on the left and right. This could have resulted in differences in polymerization at the bonding interface, which is the deepest part of the sample.

An additional step where error could have been introduced was during transportation of the samples. For each visit, samples were prepared in the dental clinic at Fort Hood, TX, and then carefully individually packaged in bubble wrap. Samples were then transported to the DECS laboratory in San Antonio, TX, where the bond strengths were tested. Any movement during transport could have introduced stress into the system and possibly reduced the bond of the sample. Ideally, sample preparation and bond strength testing would have both been conducted at the DECS facility to eliminate error from transportation of the samples. However, due to time restraints, we could only procure enough time at DECS for breaking of the samples and thus, preparation needed to be completed beforehand at a separate location.

One last step where error could have been introduced was during measurement of the samples with the digital calipers. Exact measurement of the diameter of each sample was needed for calculation of the bond strength in megapascals (N/mm^2). In this study, these measurements were taken before breaking each sample. Contacting the sample with the arms of the digital caliper may have introduced a small degree of stress and could very well have affected the bond strength. This could have been avoided by measuring the diameter of the sample after it was sheared off. However, this would have proven difficult given that several of the samples flew off once they de-bonded and could not be recovered. If a jig could be fabricated to catch the sample and allow for recovery and measurement, then this would certainly be an improvement to the protocol used in this study.

Once all samples were de-bonded, the ceramic substrate was evaluated under a microscope to determine method of failure. With the hydroxyapatite nanofibers embedded in NovaPro Flow, one would expect this material to have less cohesive failures within the composite itself. This was indeed the case, as both NovaPro Flow and Filtek Ultra Supreme Flowable both had only one cohesive failure. Henry Schein Natural Elegance had five cohesive failures, but these results were not statistically significant.

NovaPro Flow is being advertised as a better alternative to the nanohybrid composites commonly used in dentistry due to its novel technology. In this study, Henry Schein Natural Elegance exhibited the highest bond strengths, but the results were not statistically significant. These results can lead clinicians to conclude that similar results can be expected when repairing anterior ceramic restorations with either a nanohybrid or nanofiber-reinforced nanohybrid composite. Based on the results of this study, NovaPro Flow is an acceptable treatment alternative for repairing anterior ceramics. It may not be a superior alternative as advertised by its manufacturer, but it gives clinical results similar to the widely used nanohybrid composites.

Ultimately, the clinician must decide on a case-by-case basis whether to repair a ceramic restoration or to completely replace it.

Further research is warranted with NovaPro Flow, given that it is a relatively new composite and is being advertised for a wide range of uses. Our protocol tested the bond strength of the material in response to shear stress. However, due to the dynamic forces of occlusion, a micro-tensile bond strength test of NovaPro Flow may also be indicated. Teeth and dental restorative materials experience a great deal of tensile forces, so this test may reveal more information about NovaPro Flow and its mechanical properties. Additional areas to explore would include hardness tests, flexural strength tests, bonding to other ceramics or tooth structure, and in vivo short/long-term survival studies.

CONCLUSION

The results of this in-vitro study lead one to conclude:

1. There is no statistically significant difference in the bond strengths between NovaPro Flow, Filtek Supreme Ultra Flowable, and Henry Schein Natural Elegance when bonded to IPS Empress CAD.
2. There is no statistically significant relationship between bond strength and failure mode in the aforementioned flowable composites.

The findings in this study lead to the acceptance of both null hypotheses #1 and #2.

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