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Comparison of Enamel and Dentin Shear Bond Strengths of Current Dental Bonding Adhesives From Three Bond Generations

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Clinical Relevance

Dentists use dental bonding agents (DBAs) in most operative/restorative procedures. Knowing the strengths and weaknesses of such commonly used materials helps clinicians choose the appropriate DBA for optimal clinical outcomes.

SUMMARY

Objective: Durability is still a major challenge in adhesive dentistry. One of the biggest areas of development has been to simplify the bonding process by using all-in-one adhesives. The aim of this study was to compare the shear bond strength (SBS) to dentin and enamel of nine dental bonding agents (DBAs) from three generations after simulated aging.

Methods and Materials: For this study, 108 sound extracted human molars were randomly assigned to nine groups (n=12). The sample teeth were mounted in self-cure acrylic resin sectioned to provide paired enamel and dentin samples. All samples were polished with 240 and 600-grit silicon carbide sandpaper and randomly grouped according to the product and substrates (enamel or dentin). Herculite Ultra resin composite cylinders were bonded on each test surface, stored in 100% humidity at 37°C for 24 hours, and then thermocyled for 1,000 cycles at 5°C and 55°C. SBS testing was performed using an Ultratester at a crosshead speed of 0.5 mm/min. Statistical analysis included two-factor analysis of variance, one-sample Wilcoxon and Kruskal-Wallis tests, and the Scheffe post hoc test at an alpha level of 0.05 using SAS version 9.2.

Results: Significant differences in SBS were observed between the sixth- and seventh-generation DBAs (*p*=0.002) but not between the sixth- and fourth-generation DBAs. Scheffe post hoc tests for the sixth-generation DBAs showed that some DBAs yielded significantly higher enamel SBS than others, but not as much as dentin SBS. As for the seventh-generation DBAs, similar post hoc tests showed

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significant variations in SBS between substrates (enamel and dentin) and DBAs tested. Significant main effects were also found for the different substrates for the fourth-generation (F[1,96]=10.532; *p*=0.003) and seventh-generation (F[1,96]=22.254; *p*<0.001) DBAs, but not for the sixth-generation DBAs (F[1,96]=1.895, *p*=0.172). The SBS was higher on dentin than enamel for the fourth- and seventh-generation DBAs.

Conclusion: As expected, fourth- and sixth-generation DBAs generally showed stronger SBS values than the seventh-generation all-in-one DBAs. The new sixth-generation DBA OptiBond XTR (Kerr) showed strong SBS values to both substrates and performed well in comparison to the other DBAs tested.

INTRODUCTION

The past two decades have seen rapid progress to improve dental adhesive bonding materials and technologies as well as to simplify clinical application for dentin and enamel. The major shortcoming of contemporary adhesive restoratives is their limited durability *in vivo*.[1] The most cited reasons for failure of adhesive restorations are loss of retention and marginal adaptation.[2,3] Consequently, a viable approach to prolong the clinical lifetime of dental adhesives is to focus on improving the long-term stability of the bond of these biomaterials to tooth hard tissues, especially dentin.

The immediate bonding effectiveness of most current adhesive systems is quite favorable regardless of the adhesive used.[4] However, when adhesives are tested in simulated laboratory studies and clinical trials, the bonding effectiveness of some materials appears dramatically low, whereas the bonds of other materials are more stable.[5,6]

Although many advances have been made in adhesive technology since Michael Bonocoure introduced acid etching in 1955 and Ray Bowen introduced bisphenol A glycidyl methacrylate (Bis-GMA) to dentistry in 1962, the bond interface remains the biggest challenge when placing an adhesive restoration.[7] Water sorption is thought to be the main factor destabilizing the adhesive–tooth bond, although the actual interfacial degradation mechanisms are not completely understood.[8,9] Other factors to consider are all the chemical and mechanical challenges inherent to the oral environment, such as moisture, masticatory stresses, changes in temperature and pH, and dietary and chewing habits.[1]

One of the biggest areas of development has been to simplify the bonding process by use of all-in-one adhesives, but according to the review published by Van Meerbeek and others, "the conventional 3-step etch & rinse adhesives and 2-step self-etch adhesives are still the benchmarks for dental adhesion in routine clinical practice."[10] All-in-one adhesives have certainly improved over the past decade, and the development of functional monomers with strong and stable chemical affinity to hydroxyapatite is without doubt a valuable direction to continue for the improvement of dental adhesion.

The aim of this study was to compare shear bond strengths (SBSs) to dentin and enamel of nine dental bonding agents (DBAs) from three generations, including a new sixth-generation Optibond XTR (Kerr, Orange, CA, USA), after simulated aging with thermocycling. The null hypotheses were that there would be no significant differences in SBS among the three DBA generations tested, and that there would be no significant differences in SBS between enamel and dentin substrates from the three DBA generations tested.

METHODS AND MATERIALS

A total of 108 extracted human molars were randomly assigned to nine groups (n=12). The teeth were selected in the following manner: the crowns were assessed under magnification (Surgitel 2.75×, Loupes GSC Corp, Ann Arbor, MI, USA), and the teeth with visible caries, cracks, or tooth structure anomalies were excluded from the study.

The sample teeth were mounted in an Ultradent mold (Ultradent Products, South Jordan, UT, USA) using self-cure polyethyl methacrylate diethyl phthalate (PMDP) acrylic resin (Esschem, Linwood, PA, USA) positioning the facial or lingual surface (whichever was flatter) to be exposed for the enamel bond surface. They were then sectioned mesiodistally at approximately 4 mm distance from the enamel surface. The enamel sections were then remounted in the acrylic molds in order to fit the Ultradent bonding jig so they could be tested for SBS with the Ultratester (Ultradent Products). The remaining portion of the sectioned tooth became the dentin sample. This made for a total of 216 test surfaces providing paired enamel and dentin samples from each tooth. Sample sectioning was done with a water-cooled diamond wheel saw (Leitz 1600, Wetzlar, Germany).

The enamel surfaces were polished with 240-grit silicon carbide (SiC) sandpaper until a flat area of

Table 1: *Dental Bonding Adhesive Systems: Composition, pH, and Protocols* [a]

Product/ Generation	Etch/ Rinse	Primer	Self-etch/ Primer	Adhesive/ Light Cure	Etch-Prime-Adhesive/Light Cure	Primer pH
Optibond FL (Kerr, Orange, CA, USA)/4th	15 s/10 s	15 s scrub	—	15 s/20 s	—	2.0
Optibond FL (alternate) Enamel without primer/ 4th	20 s/10 s 20 s dry	—	—	10 s /20 s	—	—
Optibond XTR (Kerr, Orange, CA, USA)/ 6th	—	—	20s scrub	15s/10s	—	1.6
Clearfil SE (Kuraray America, Inc., New York, NY USA)/ 6th	—	—	20s	Apply/10s	—	2.0
SE Protect (Kuraray America, Inc., New York, NY USA)/ 6th	—	—	20 s	Apply/10 s	—	2.0
Prelude (Danville Materials, San Ramon, CA, USA)/6th	—	—	10 s scrub	10 s scrub/10 s	—	2.0
Xeno IV (Dentsply Caulk, Milford, DE, USA)/ 7th	—	—	—	—	15 s scrub ×2/10 s	2.3
iBond SE (Heraeus Kulzer, South Bend, IN, USA)/ 7th	—	—	—	—	20 s scrub/20 s	1.6
Prompt-L-Pop (3M ESPE, St. Paul, MN, USA/ 7th	—	—	—	—	15 s scrub, second layer/10 s	1.0
Futura Bond DC (VOCO America, Inc., Briarcliff Manor, NY, USA)/7th	—	—	—	—	20 s scrub/10 s	1.5

[a] *Air drying for 10 seconds was used after all primer applications, and gentle air thinning was used when all adhesive applications were done.*

approximately 5 mm in diameter was established. The dentin surfaces were also polished with 240 grit sandpaper and copious amounts of water. Both enamel and dentin surface groups were then polished with 600-grit SiC sandpaper with copious amounts of water. The samples were grouped by substrate pairs and labeled according to the product and substrate (enamel or dentin) for accurate identification. They were then hermetically sealed and stored in 100% humidity at 37°C. Each group was bonded within 24 hours of surface preparation.

Next, the adhesive systems were used according to manufacturers' instructions for each test group as seen in Table 1. Ultradent SBS test molds (Ultradent Products) were used to build resin composite cylinders 2.38 mm in diameter × approximately 2.0 mm in height with Herculite Ultra A2 Enamel (Kerr) bonded on each test surface. The resin composite cylinders were light-cured for 40 seconds using a dental halogen curing light (OptiLux 500, Kerr) that was tested regularly to ensure 420-460 mW/cm^2 for 40 seconds from 1.0 mm distance.

After sample bonding, the specimens were stored in 100% humidity at 37°C for 24 hours then thermocyled for 1,000 cycles at 5°C and 55°C with a 30-second dwell time. The samples were then submitted to SBS testing at room temperature using an Ultratester testing machine (Ultradent Products) set to operate at a 0.5 mm/min crosshead speed until bond failure occurred. Once the SBS testing was done for the fourth-generation enamel group, the enamel surfaces were re-prepared according to the same protocol, rebonded with 20 seconds etch and rinse, submitted to 20 seconds strong air dry, and then bonded by the same protocol using the adhesive only (no primer). In regards to reusing the enamel samples for comparing an alternative protocol, this was done to make an accurate comparison with the same substrate surfaces. Because enamel has a very low level of organic constituents, and the samples were kept under controlled humidity with a short storage time between bond testing and rebonding, we believed these factors would have little effect on the results.

The statistical tests of hypotheses regarding the SBS data were performed using a two-factor (between and within) analysis of variance (ANOVA) of ranked data. Comparisons between dentin and enamel were assessed using statistical procedures

Table 2: *Shear Bond Strength (SBS) Summary*					
Generation	**Product**	**Enamel SBS**	**SD**	**Dentin SBS**	**SD**
Fourth	Optibond FL (Kerr)	27.1	9.7	38.9	8.6
Fourth	Optibond FL (alternate)[a]	28.1	5.7	NA	NA
Sixth	Optibond XTR (Kerr)	34.1	7.8	33.4	8.8
Sixth	Clearfil Protect Bond (Kuraray)	36.7	5.2	30.7	8.5
Sixth	Clearfil SE Bond (Kuraray)	30.7	8.5	27.6	7.1
Sixth	Prelue (Danvile)	18.5	10.8	34.5	7.4
Seventh	Xeno IV (Detsy Caulk)	14.4	5.4	33.8	9.2
Seventh	Prompt L Pop (3M ESPE)	24.6	9.5	27.1	11.3
Seventh	Futurabond (Voco)	13.1	8.9	14.9	6.7
Seventh	Ibond Self Etch (Heraeus)	14.6	9.7	16.8	13.2

[a] *Alternative protocol without primer.*

for related samples (one-sample Wilcoxon signed ranks test). Comparisons between DBAs were conducted with the Kruskal-Wallis procedure for independent samples and the Scheffe post hoc test for the data+ between bond generations. All the tests of hypotheses were two-sided and conducted at an alpha level of 0.05 using SAS version 9.2 (SAS Institute, Cary, NC, USA). The samples that failed before testing were given a zero value but were included in statistical analysis. This occurred during the thermocycling process and mainly with the seventh-generation bonding adhesive systems.

RESULTS

Table 2 summarizes the results. Significant differences were detected in SBS between groups regardless of the substrates, generations, and DBAs tested ($p<0.001$). Significant differences were also detected in the SBS between some of the enamel groups and between some of the dentin groups ($p=0.002$) as depicted in Figures 1 and 2. Only two of the nine study groups demonstrated a SBS difference that was significantly different from zero when dentin was compared to enamel ($p<0.05$) (Figure 3).

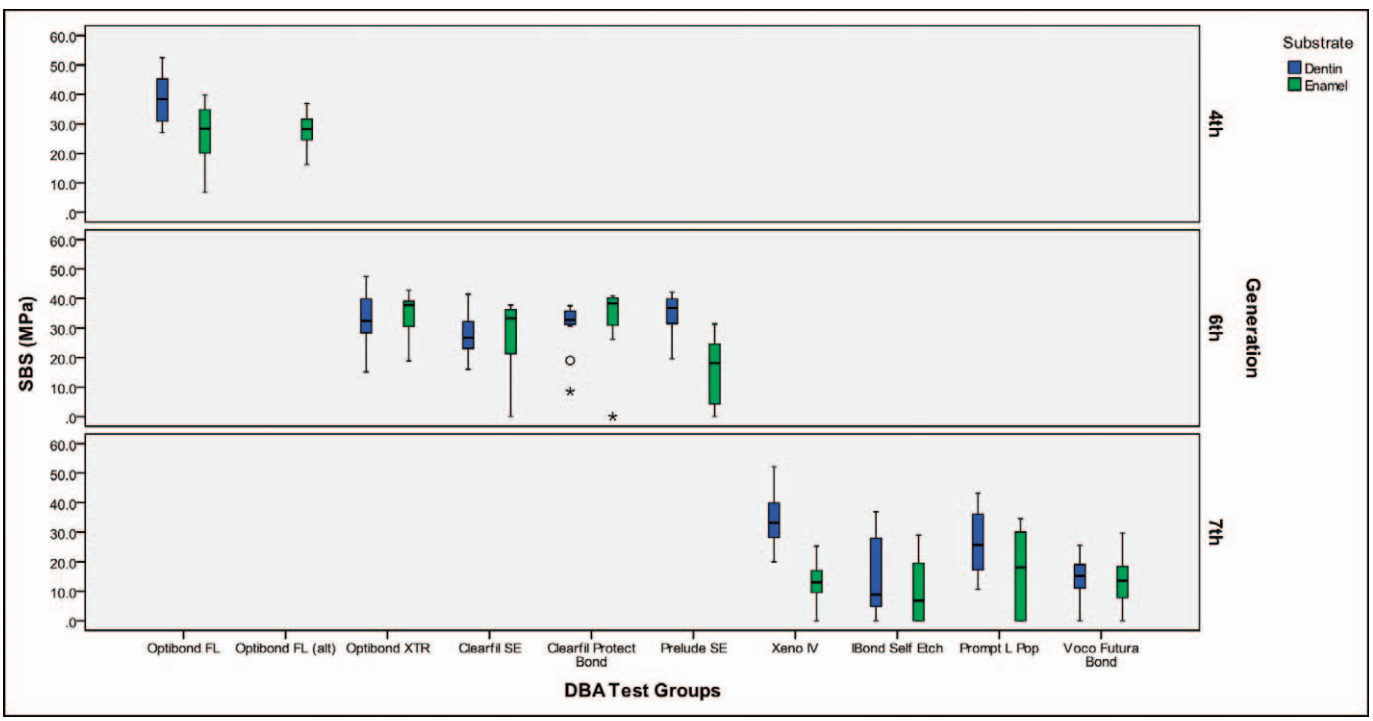

Figure 1. *Shear bond strength of DBAs according to generation (MPa). The * and ⁰ indicate outliers in the sample. Use of nonparametric statistics and analysis of ranked data reduces the bias of outliers on central tendencies. These data were included in the statistical analysis.*

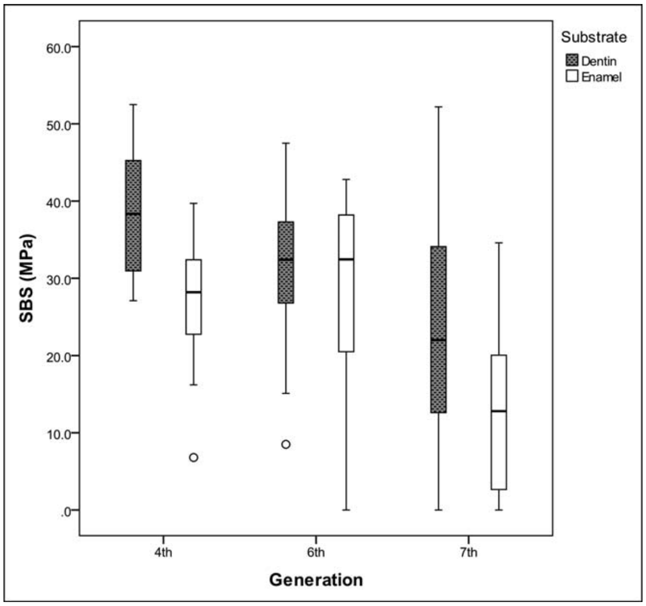

Figure 2. *Shear bond strength of DBAs pooled by generation and substrate. The 0 indicate outliers in the sample. Use of nonparametric statistics and analysis of ranked data reduces the bias of outliers on central tendencies. These data were included in the statistical analysis.*

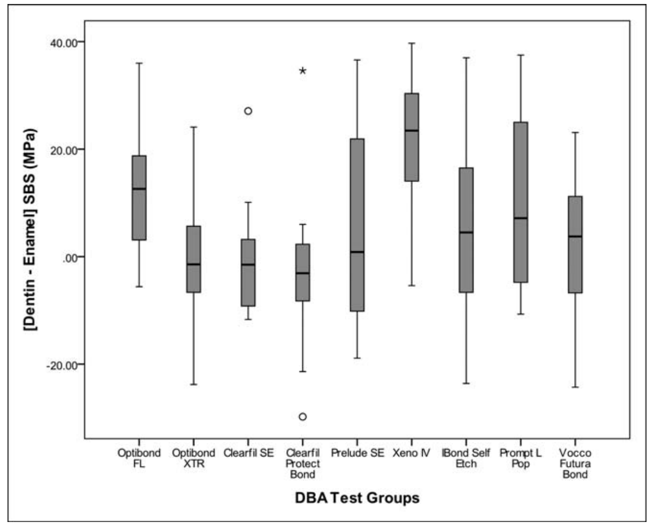

Figure 3. *Shear bond strength comparison of paired dentin and enamel. Values <0 indicate that the enamel SBS values were stronger than the dentin SBS values. The * and 0 indicate outliers in the test groups. Use of nonparametric statistics and analysis of ranked data reduces the bias of outliers on central tendencies. These data were included in the statistical analysis.*

Effect of Product on Bond Strength

The dependent variable for this analysis was the rank of SBS as measured in megapascals (MPa) and was used to test the effect of independent variables, which are the bonding agents, as "adhesive product" or "DBA" and enamel and dentin as "substrate." The SBS measurements were analyzed using a two-factor independent ANOVA within each generation group. The first factor was the adhesive product (nine total; between DBA groups), and the second factor was the substrate (enamel, dentin; within DBA groups). Figure 1 provides a summary of these results. Statistically significant differences in bond strength were observed between the DBAs of the sixth-generation DBAs [F (3, 96) =4.202, p=0.008] and seventh-generation DBAs [F (3, 96) =7.199, p<.001], but not between the fourth- and sixth-generation DBAs.

Scheffe post hoc tests for the sixth-generation DBAs showed that Optibond XTR (Kerr, Orange, CA, USA) yielded significantly higher enamel bond strength than Prelude SE (Danville Materials, San Ramon, CA, USA) (p=0.037). Clearfil Protect Bond (Kuraray America, Inc., New York, NY USA) also yielded adequate enamel bond strength, as did Prelude SE, with no statistically significant difference (p=0.093); however; dentin SBS for Prelude SE was among the highest in its generation group. For the seventh-generation DBAs, similar post hoc tests showed that Xeno IV (Dentsply Caulk, Milford, DE, USA) had significantly higher bond strength than IBond Self Etch (Heraeus Kulzer, South Bend, IN, USA) (p=0.010) and Voco Futura Bond (p=0.009). Prompt-L-Pop also had significantly higher bond strength than IBond Self Etch (p=0.032) and Voco Futura Bond (VOCO America, Inc., Briarcliff Manor, NY, USA) (p=0.029). No other pairwise comparison within the sixth- or seventh-generation DBAs yielded notable results.

The SBS measurements were also analyzed using a two-factor independent ANOVA between generations. Figure 4 depicts the results showing that there was no significant difference between pooled generation groups of fourth- and sixth-generation DBAs; however, the pooled generation group SBSs of seventh-generation DBAs were significantly lower than those of the fourth and sixth pooled generation groups.

Effect of Substrate on Shear Bond Strength

Significant effects were also found for the different substrates for the fourth [F (1, 96) =10.532, p=0.003] and seventh [F (1, 96) =22.254, p<0.001] generations; This was shown by the fact that the dentin SBS was significantly higher than the enamel SBS in both the fourth and seventh generations. But for the sixth generation [F(1,96)=1.895, p=0.172],both the dentin and enamel substrates had almost

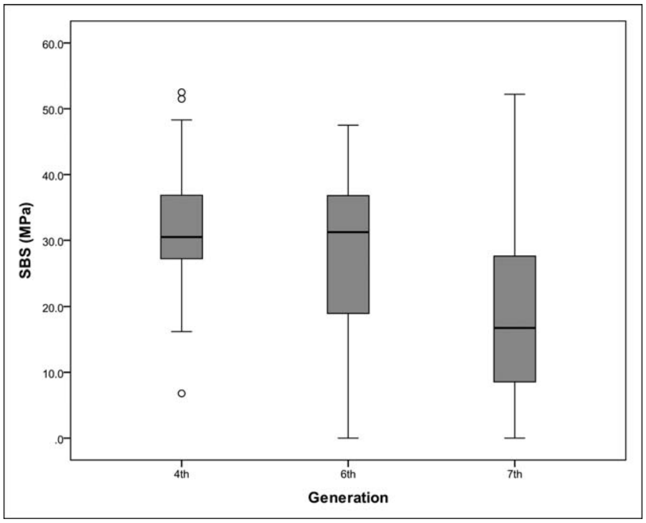

Figure 4. *Shear bond strength of DBAs pooled by generation. There was no significant difference between fourth- and sixth-generation adhesives when substrates were pooled; however, SBS values were significantly lower for seventh-generation adhesives. The * and ^{0} indicate outliers in the sample. Use of nonparametric statistics and analysis of ranked data reduces the bias of outliers on central tendencies. These data were included in the statistical analysis.*

identical SBS (see Figure 2). Also of interest was that the two DBAs with the highest combined enamel and dentin SBS and lowest variability were Clearfil SE Protect and Optibond XTR. With the alternative bonding protocol of the fourth-generation DBA to enamel (20-second etching time, 20-second air-drying time, and adhesive without primer) a significant SBS value was not observed between the primer plus adhesive manufacturer's recommended protocol and the alternative adhesive only protocol for Optibond FL (Kerr, Orange, CA, USA), 27.5 MPa vs 28.1 MPa, respectively.

DISCUSSION

Difference Between All Groups

As stated in the introduction, the null hypotheses for this study were that there would be no significant SBS differences between the three DBA generations tested, and that there were no significant SBS differences between enamel and dentin substrates from DBAs of the three adhesive generations tested. However, significant differences were detected in SBS between groups regardless of the mentioned variable DBAs ($p<0.001$). This is not surprising as manufacturers are continually trying to come up with DBAs that have improved physical and mechanical properties as well as simplifying the protocol for ease of use. Numerous studies have been done to test these DBAs and to alter the original protocols. Because of variations in the protocols and diverse formulations of primers and adhesives, it is expected that some will simply work better than others. And that is what was observed in this study as well as others.[10-14]

One aspect in the design of this study that was specifically done to add more power to the results was pairing substrate samples. With any study, whether it is *in vitro* or *in vivo*, there will always be confounding factors, such as age of the test tooth, storage media and duration, cultural and environmental factors of the person from whom the tooth was obtained, and sample-processing procedures. These issues are difficult, if not impossible, to account for statistically. To minimize these confounding factors, care was taken to pair the enamel and dentin samples in order that SBS comparisons of these substrates would be more meaningful.

It has been reported that self-etch bonding systems have a significantly lower SBS to enamel than the gold standard total etch fourth-generation adhesives.[15] This was not the case in our study, as our data showed higher enamel bond strengths, though not significant, with some of the self-etch sixth-generation DBAs (Figures 1 and 2). For example some of the highest bonds to enamel in this study were with the new Optibond XTR self-etch, even though it is considered a mild self-etch adhesive with a pH of 2.4. According to the manufacturer, the pH drops to 1.6 during the primer application, resulting in enhanced enamel etching and bonding.

Perhaps this is because the primer has hydrophilic comonomers including mono- and di-functional methacrylate monomers, in a solvent of water, ethanol, and acetone. This three-part solvent is believed to enhance its self-etching capability by facilitating penetration of the hydrophilic monomers into the tooth, which should lead to high bond strengths. The Optibond XTR hydrophobic adhesive layer contains a balanced or neutral chemistry in that it has a pH of 3.3 in the bottle but the pH increases to 6.5-7.0 after application and light curing.[16] This seems to complement the primer by stabilizing the bond in a moist oral environment.

Difference Among Enamel Groups

Significant differences were detected in the SBS between some of the enamel groups, as shown in Figure 1 ($p<0.001$). No significant difference in SBS was observed between the pooled fourth- and sixth-generation DBAs with the enamel substrate (Figure 2). The SBS to enamel was significantly lower ($p=0.003$) with all of the seventh-generation adhesives compared with the previous generations (fourth and sixth) with exception of Prelude SE. The median SBS for the fourth-generation adhesive at the enamel was lower, but not to a statistically significant degree, than that of the sixth-generation adhesives. When the alternative protocol for bonding to enamel (adhesive only to dry etched enamel) was used in this study, the mean SBS increased, but the difference was not statistically significant. Historically, concerns have been expressed regarding the short- and long-term bonding effectiveness of self-etch adhesives to unetched and or unprepared enamel[17] especially the mild self-etch class.

Difference Among Dentin Groups

Significant differences were also detected in the SBS between some of the dentin groups shown in Figure 1 ($p=0.002$). The fourth-generation group had the highest SBS, which was significantly stronger than the sixth-generation groups pooled (Figure 2); however, it was not higher than Prelude by itself (Figure 1), and both the fourth and sixth generations had significantly higher SBS than the seventh-generation groups. These results are expected from review of other studies. In a 2005 review, De Munck and others[7] concluded that the three-step etch-and-rinse adhesives are still the gold standard in durability and that any kind of simplification, such as one-step all-in-one adhesives, results in loss of bonding effectiveness and durability. They stated, "Only the two-step self-etch adhesives approach the gold standard and do have some additional clinical benefits."[7]

This may be due to the finding that dentin collagen fibrils contain inactive proforms of proteolytic enzymes called matrix metalloproteinases (MMPs). When fully mineralized, the MMPs in the dentin matrix are inactive. Most of the one-step all-in-one adhesives are highly acidic. These MMPs are exposed and activated by acid-etching or self-etch primers during adhesive application process.[18] Therefore, the stronger the acid the more MMPs are released, resulting in adhesion breakdown over time. A possible reason the fourth- and sixth-generation adhesives have greater durability than the one-step all-in-one adhesives is that they get better infiltration and adaptation (wetting) to the exposed collagen fibrils because their hydrophilic primer is separate from the hydrophobic adhesive. Other factors have also been proposed for their lower performance, such as inhibition of polymerization of the restorative composite being bonded due to the high acidity of seventh-generation DBAs, an insufficiently thick adhesive layer, phase separation between hydrophilic and hydrophobic ingredients, and resultant sensitivity to hydrolysis.[19]

Depth of penetration of the monomer into the hybrid layer, however, may not be the main determining factor of bond strength. Yoshida and others[20] have described another bonding mechanism in that self-etch adhesives, especially mild ones, demineralize dentin only partially, and that leaves hydroxyapatite partially attached to collagen. As some of the hydroxyapatite remains available for chemical interaction between the functional monomer's carboxyl groups it can form an ionic bond with the calcium of the residual hydroxyapatite. So it is theorized that the less soluble the calcium salt of the acidic molecule, the more intense and stable the molecular adhesion to a hydroxyapatite-based substrate.[20] This certainly could be a big factor in explaining the variance in DBA bond strengths.

In a more recent review, Van Meerbeek and coworkers[10] stated: "While micromechanical interlocking remains the primary adhesive mechanism, mild self-etch adhesives (sixth generation), in particular, may additionally make use of chemical interaction that especially contributes to the long-term stability of the bond. Although one-step adhesives are the simplest to use, their adhesive performance is less than that of multistep adhesives, primarily due to lower bond strength and durability, phase separation phenomena with hydroxy-ethyl-methacrylate (HEMA)-poor/free formulations, enhanced water sorption with HEMA-rich formulations, and a reduced shelf life."

The results of the current study also showed that the sixth-generation adhesives, including the new Optibond XTR, appear to perform very well in comparison to the fourth-generation adhesives. The seventh-generation all-in-one type adhesive systems are more susceptible to water sorption and, as a result of nanoleakage, are more prone to bond degradation and tend to fail prematurely compared with their fourth- and sixth-generation counterparts.[9]

Difference Between Paired (Enamel vs Dentin) Groups

In the present study, the enamel SBS was generally weaker than the dentin SBS in the fourth- and seventh-generation groups, but they were almost equal in the sixth-generation groups (Figure 2). The current study paired the enamel and dentin substrates from the same tooth to allow a more powerful comparison between the SBS between the two substrates. We found that only two of the nine study groups demonstrated a bond strength difference between the two substrates (Figure 3) that was significantly different from zero when dentin was compared to enamel: Optibond FL (p=0.012) and Xeno IV p=0.008), shown in Figure 3. For these two groups, the bond strength for dentin was significantly higher than that measured for enamel. In a recent study that involved bonding to dentin and enamel, Hanabusa and others[11] found that by pre-etching the enamel with phosphoric acid etch-and-rinse, the enamel bond and dentin bond strengths were almost equal. However the marginal integrity of bonded enamel is still greater than marginal integrity of dentin and less prone to hydrolytic breakdown.[21]

Difference Between Generations (Total)

Significant differences were detected in the bonding strength between the generations when both enamel and dentin substrates were pooled (p=0.002). Both the fourth-generation (p<0.001) and sixth-generation (p<0.001) groups demonstrated significantly higher SBS than the seventh generation. No significant difference was observed between the fourth and sixth generations (p=0.781). Figure 4 depicts the SBS of the generations with enamel and dentin values pooled. In almost every case, the dental bonding systems that combine the primer and adhesive have lower SBS values and longevity, The gold standard in dental bonding is still the fourth generation, followed closely by the sixth generation.[7] In both of these classes of dental bonding agents, the primer and adhesives are placed as two separate steps. Perhaps one of the biggest factors for this is that the chemistry of a one-bottle system is not stable and is prone to hydrolyzation; this weakens the ability of the acidic monomers to etch as they prime the tooth substrate.[22] With this in mind, some manufacturers (eg, 3M ESPE with Prompt-L-pop) have altered the packaging to address this problem with some success.

Difference Between Generations (Enamel vs Dentin)

Another finding in this study that was contrary to the null hypothesis was that significant differences were detected in the enamel bonding strength between the generations (p<0.001). The fourth and sixth generations were not significantly different from each other; however, the sixth-generation DBAs, with their self-etch primers, had higher mean SBS values (Figure 2). One might expect that the fourth-generation etch-and-rinse product would have the highest SBS to enamel because of its deeper etching ability. When bonding to enamel, an etch-and-rinse approach is definitely preferred because the micromechanical interaction appears sufficient to achieve a durable bond to enamel. On the other hand, the mild self-etch (sixth generation) approach seems to provide superior performance when bonding to dentin. These mild self-etch adhesives also chemically interact with residual hydroxyapatite because mild self-etch adhesives demineralize dentin only partially, leaving a substantial amount of hydroxyapatite crystals around the collagen fibrils. This remains available for possible additional chemical interaction.[23] The resulting twofold bonding mechanism, that is, micromechanical and chemical adhesion, is believed to be advantageous and definitely contributes to bond effectiveness and durability.[9] This is similar to the twofold bond mechanism seen with glass ionomer restoratives. This may explain why the mild self-etch (sixth generation) adhesive systems in this study had bonds equal to or higher than those of the fourth-generation etch-and-rinse systems. The all-in-one seventh-generation DBAs, with their stronger pH, do not seem to share the twofold bonding mechanism; therefore, their bond effectiveness and durability are not expected to be as good.

CONCLUSIONS

The null hypotheses of this study that there would be no significant difference with SBS between three adhesive generations of DBAs and between substrates (enamel and dentin) were rejected. According to the results of the current study, there were differences between the SBS of the enamel and dentin substrates and the DBA generations. This study also showed that SBS differed significantly between DBA generations more so than between the substrates tested. As expected from previous studies, fourth- and sixth-generation multistep DBAs generally showed stronger SBS values than the seventh-generation all-in-one DBAs. Also of note, the new sixth-generation DBA, OptiBond XTR, showed strong SBS values to both enamel and dentin substrates and performed well in comparison to the other DBAs tested.

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Conflict of Interest

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

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